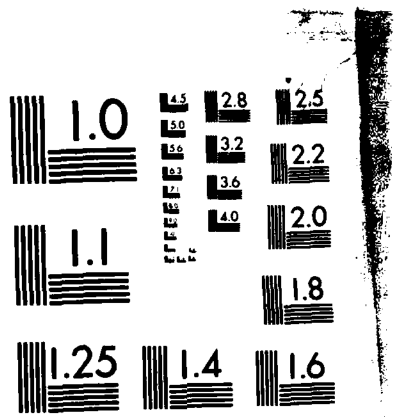
AD-A133 232 DISTRIBUTION OF WATER USE AT REPRESENTATIVE FIXED ARMY INSTALLATIONS(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL J T BANDY ET AL. AUG 83 1/2

UNCLASSIFIED CERL-TR-N-157 F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

construction
engineering
research
laboratory

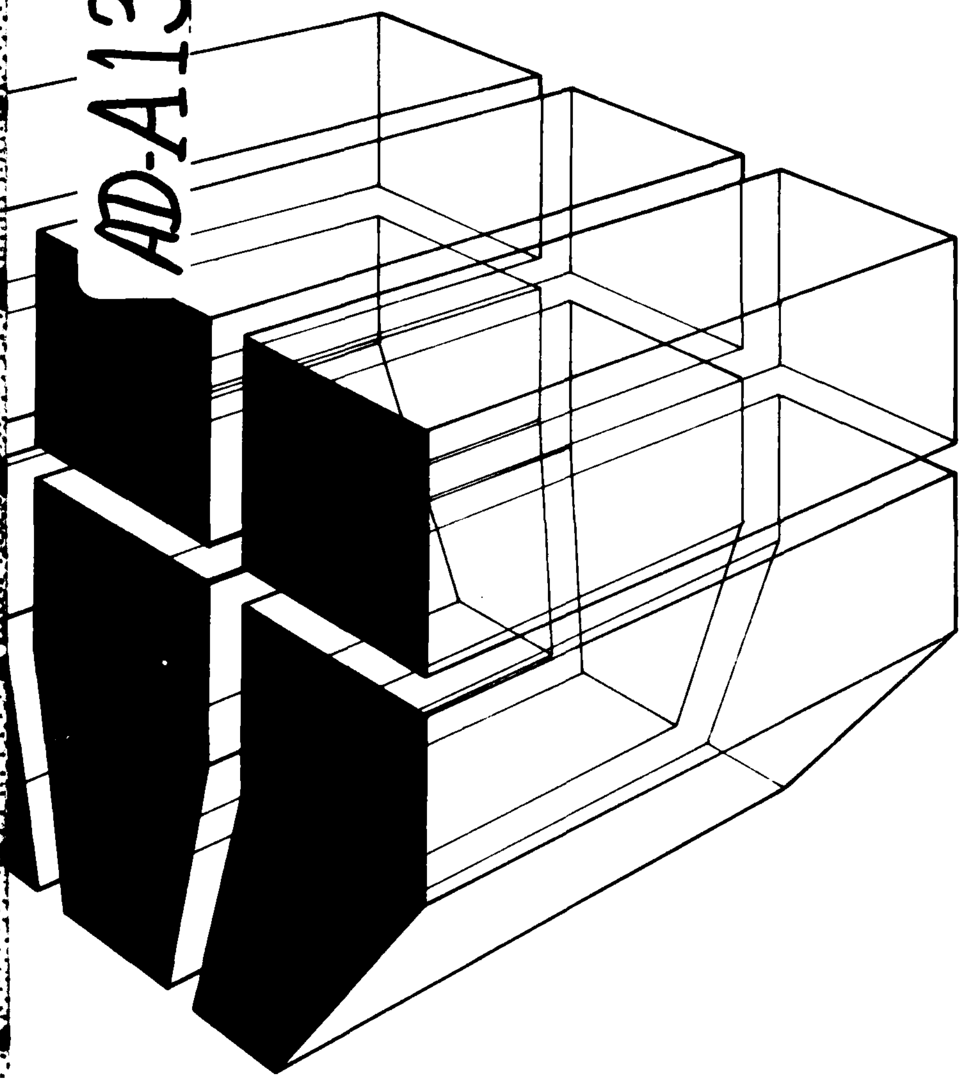
United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

Technical Report N-157
August 1983

Water Conservation and Reuse Guidelines

AD-A133232

DISTRIBUTION OF WATER USE AT REPRESENTATIVE FIXED ARMY INSTALLATIONS



by
John T. Bandy
Richard J. Scholze

Approved for public release; distribution unlimited.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-157	2. GOVT ACCESSION NO. A133 232	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DISTRIBUTION OF WATER USE AT REPRESENTATIVE FIXED ARMY INSTALLATIONS		5. TYPE OF REPORT & PERIOD COVERED FINAL 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John T. Bandy Richard J. Scholze		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Construction Engr Research Laboratory P.O. Box 4005 Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4A762720A896-A-031
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE August 1983 13. NUMBER OF PAGES 107 pages
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service
Springfield, VA 22161

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

water consumption
Ft. Bliss, TX
Ft. Lewis, WA
Ft. Carson, CO
Ft. Bragg, NC

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents research conducted by the U.S. Army Construction Engineering Research Laboratory (CERL) to (1) examine the implications of current water use for mobilization planning; (2) determine what proportion of the potable water consumed at a typical Army fixed installation goes to each major category of use; (3) determine how these proportions change during the year; and (4) present this information in an easily understandable and useful form.

(Cont'd)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

To do this, CERL personnel visited Forts Bliss, Bragg, Carson, and Lewis to collect historical water use data and to interview installation personnel. Statistical analyses were performed on the collected water use data to provide the information needed to develop water use distributions and to evaluate the present mobilization planning factors.

It was found that troop and family housing and irrigation are by far the biggest water consumers on the installation. Industrial activities are also large water users. It was also found that irrigation causes the most variation in water demand, in some cases accounting for half the water use during the summer. There is also a wide range in individual use of water. If excessive use could be moderated, significant savings could be realized. Analysis of current mobilization water supply showed that currently assumed requirements may be too low.

FOREWORD

This research was conducted for the Assistant Chief of Engineers under Project 4A762720A896, "Environmental Quality Technology"; Technical Area A, "Installation Environmental Management Strategy"; Work Unit 031, "Water Conservation and Reuse Guidelines." The applicable QCR is 6.27.20A. The work was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (CERL). The OCE Technical Monitor was Mr. R. Newsome, DAEN-ZCF-U. Dr. R. K. Jain is Chief of EN.

Appreciation is extended to the following people for their administrative and technical assistance: Dr. E. D. Smith (CERL); Ms. Mary Staub, Fort Carson; Mr. David Hawke, Sanitary Engineer, Fort Lewis; and Mr. William Lewis, Sanitation Branch Chief, Fort Bliss.

COL Paul J. Theuer, PE is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

TABLES (Cont'd)

TABLES (Cont'd)

FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)

DISTRIBUTION OF WATER USE AT REPRESENTATIVE FIXED ARMY INSTALLATIONS

1 INTRODUCTION

Background

The U.S. Army uses more than 130 billion gal of water annually and spends more than $130 million for operation and maintenance (O&M) of its water and wastewater utilities. Despite this expense and despite the indispensability of adequate potable water supplies for present and expanded or mobilized Army fixed facilities, little is known about the Army's actual use of potable water. Knowledge of installation water use patterns is a necessary first step in identifying opportunities for water conservation.

Until recently, the water needs of Army activities were not known specifically. Very little of the water consumed on fixed installations is metered. Therefore, the U.S. Army Construction Engineering Research Laboratory (CERL) is now conducting a water use characterization study which, through metering and analysis of historical data, is providing the water use information needed to accurately evaluate current use and more realistically project future needs.

The amount of 150 gal of water per capita per day, which has been set arbitrarily by the Army, has worked fairly well in providing for the needs of peacetime installations. However, the extrapolation of this level of water use to the needs of the radically different mobilized installation is questionable. It would be preferable to derive water demand factors specific for mobilization based on an installation's mobilization mission and the known water requirements of the installation's projected activities.

This report describes the water use patterns of four representative Army installations. The information should be helpful in planning for mobilization and, more immediately, in developing drought and other water storage contingency plans.

Objectives

The objectives of this study were to (1) examine the general implications of current water use for mobilization planning; (2) determine what proportion of the potable water consumed at a typical Army fixed installation goes to each major category of use; (3) determine how these proportions change during the year; and (4) present this information in an easily understandable and useful form.

Approach

Army water use and water supply design practices were analyzed and current Army water supply planning and mobilization practices were examined. Forts Bliss, Bragg, Carson, and Lewis were then visited to collect historical water use data and to interview installation personnel. The collected water use data were then statistically analyzed to provide the information needed to develop water use distributions and to evaluate the present mobilization planning factors.

Mode of Technology Transfer

It is recommended that the information in this study be incorporated into an Engineer Technical Note. Information from this study may impact Technical Manual (TM) 5-813-1, Water Supply -- General Considerations; TM 5-660, Operation of Water Supply and Treatment Facilities at Fixed Army Installations; and TM 5-630, Repairs and Utilities -- Ground Maintenance and Land Management.

2 ARMY WATER USE

Importance of Use Characterization

The primary importance of water use characterization is to develop baseline data. Contingency planning for drought, mobilization, or other crises is more reliable when usable resources are known. Planners, forecasters, and military decision-makers can make management choices more precisely if they are aware of the complex patterns of water use. Existing resources can also be managed better when water disposition patterns are known. Current use patterns can be changed to fit a given situation.

Water loss is a problem throughout the country. Most installations lack any knowledge of the volume of water which is lost or otherwise unaccounted for. Utility billing data for commercial or other nonpost entities (e.g., PX, credit union) are often acquired by estimating. Actual meter measurements would enhance utility revenues, because the estimates are usually lower than actual consumption. Leak detection programs operated by base personnel and meter measurements of flow would show how to better distribute resources on the installation. Irrigation practices are a major concern to a conservative water budget. Many posts have no idea how much water is used for turf and lawn maintenance irrigation. Determining the fundamental water application and incorporating sound irrigation practice and precise contract specifications would lower water consumption; this would make more water available for higher-level applications.

Army Water Use

There are more than 100 fixed Army installations in the United States. Each post is like a small city, containing a large residential section with industrial, commercial, recreational, and educational facilities. Table 1 lists typical installation activities. Figure 1 summarizes water procurement and use at a representative installation.

Military installations have several unique characteristics:

1. Population may fluctuate widely between day and evening due to the large number of civilian employees.

2. Population levels vary due to maneuvers, training exercises, and leave passes.

3. The military setup enables orders to be carried out quickly.

4. There is a lack of water meters.

5. Army personnel pay fixed fees for unlimited water.

Figure 2 shows how the Army's water use has changed since 1975. Although use has fallen slightly, the total expense has risen almost 80 percent due to increases in unit costs. Family housing and irrigation are often the largest water consumers. Residential water use is concentrated in lawn watering,

Table 1

Typical Activities Related to Water and Wastewater at Army Installations

Administration/Institutional	Industrial
Unclassified office space	Vehicle washracks
Shipping and receiving facilities	Aircraft wash
Communications facilities	Steam cleaning
Command-level headquarters	Metal plating and finishing
Radar installations	Autoclaves
Military training and instruction facilities	Boilers
Hospitals	Metal cleaning
	Paint booth water wall
Wastewater Management	Air pollution wet scrubbers
	Laboratories
Sewage treatment	Cooling towers
Industrial waste treatment	Dynamometers
Wastewater disposal	Engine test cells
	Ash handling systems
	Industrial laundries
Housing	Pesticide management area
	Photographic laboratory
Family housing	Motor pools
Barracks	
Bachelor officers quarters	**Recreational**
Visiting officers quarters	
Mess halls	Swimming pools
Commercial	**Irrigation**
Commissary	Parade grounds
Post exchange	Athletic fields
Gas station	Golf courses
Laundromats	Cemeteries
Restaurant/cafeterias	Lawns
Post office	Parks
Bank	Commercial landscaping

toilet flushing, bathing, and kitchen activities. Quantities consumed vary with climate, standard of living, personal habits, family size, and inhabitants' ages. Since Army residential uses are similar to public uses, benefits from water conservation would be similar. (CERL Technical Report N-146[1] provides Army-applicable guidance.)

Irrigation consumes more than 50 percent of some bases' warm season water supply and, accordingly, that share of O&M funds. Family housing lawns,

[1] R. J. Scholze, L. J. Benson, M. A. Kamiya, M. J. Staub, and J. T. Bandy, Water Conservation Methods for U.S. Army Installations: Residential Usage and Irrigation Management, Technical Report N-146 (U.S. Army Construction Engineering Research Laboratory [CERL], 1983).

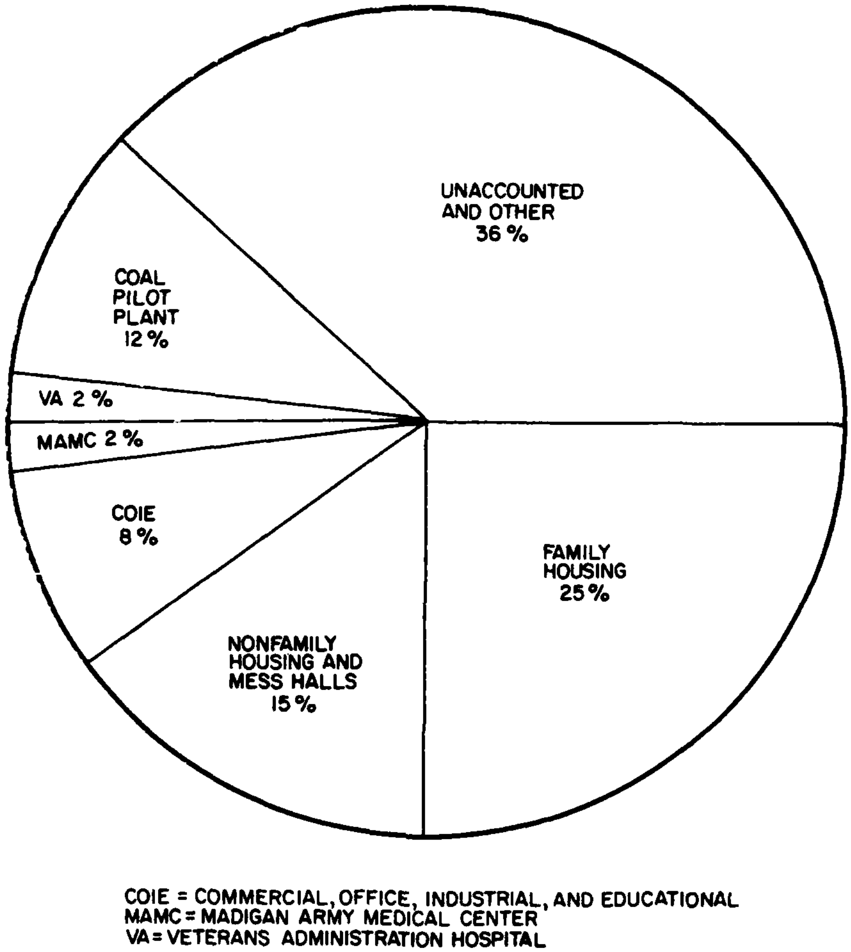


Figure 1. Procurement and use of water at a representative installation.

commercial and administrative landscaping, recreational fields and parks, golf courses, cemeteries, and parade grounds all contribute to the total turf maintenance requirements. Some bases irrigate all year, although they use lower volumes during cooler months.

There are techniques which allow more efficient use of available water and therefore decrease water consumption. Some installations have begun to use these techniques, but additional encouragement is needed. CERL Technical Report N-146 addresses water conservation for turf and lawn maintenance. Savings resulting from more efficient water use could be critical at posts with a mobilization mission or where there is a drought or water shortage. In addition, savings could be gained, because more efficient water use would reduce the need to construct new water supply lines.

Laundries and boiler plants are known users of large quantities of water. Arid locations may use air washers for air conditioning, and these use a large volume of water. Hospitals, troop barracks, and mess halls are also heavy water consumers. Industrial operations vary among installations, but major consumers in this area are washracks and cooling towers. Swimming pools also

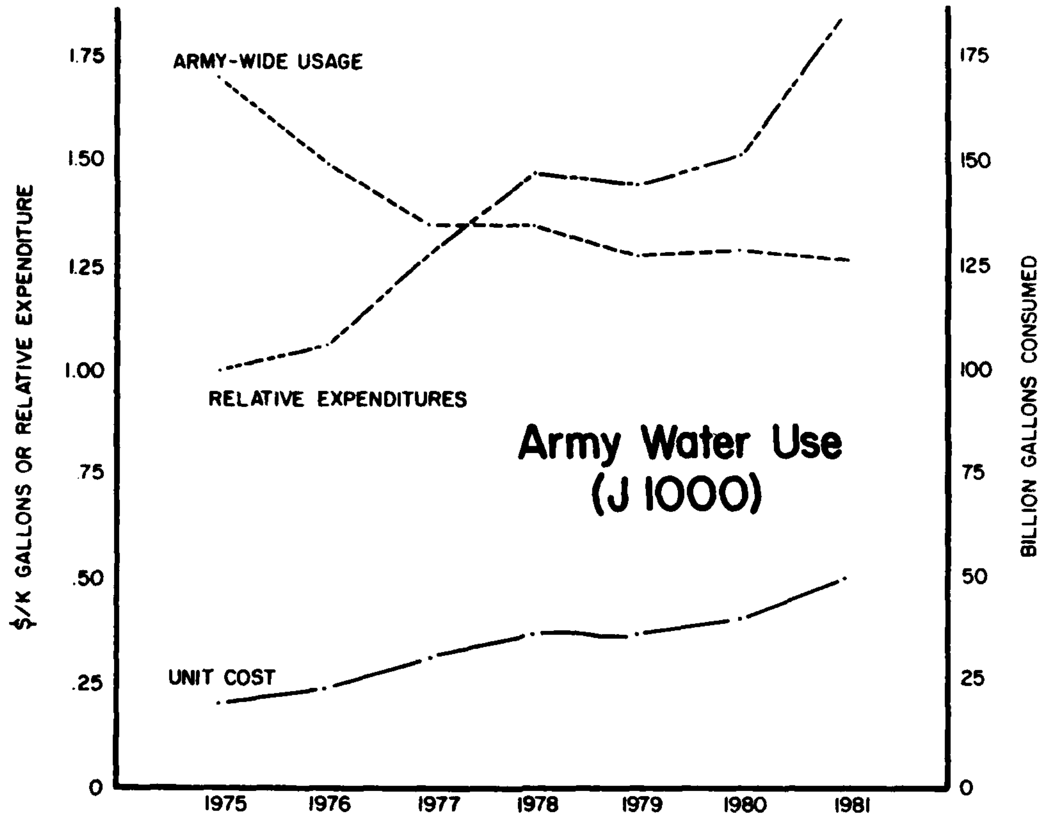


Figure 2. Change in Army water use since 1975.

consume a great deal of water, especially in arid, warm climates with high evaporative rates.

Base Selection for Army Water Use Study

Military installations throughout the continental United States were investigated to determine which ones would provide the most comprehensive information for CERL's water use characterization study. The study required installations that would represent a variety of climates, have heavy water consumption under a variety of conditions, and have a large cantonment area. To thoroughly investigate irrigation requirements, the country was divided into eastern and western areas. Three installations in the western continental United States and one installation in the eastern United States were chosen for investigation. Fort Bragg, NC, represented the humid eastern part of the United States. The western installations chosen for study were Fort Bliss, TX; Fort Carson, CO; and Fort Lewis, WA. These installations straddle the country north to south and include climates ranging from arid through humid. Irrigation for turf maintenance also uses large water volumes at all the bases chosen. Other aspects of the installations were also expected to differ (e.g., commercial, industrial, etc.).

Previous water conservation research at these installations included installation of some water meters. Fort Carson had been thoroughly metered for representative users, and one year of data had been gathered. Preliminary results were published in CERL Interim Report N-34[2] and Technical Report N-146. Fort Lewis had also been metered to a small degree and Fort Bliss to a very slight degree. The metering information helped establish consumptive values representative of a specific base. Although no post comprehensively meters every building, the information from representative buildings can establish a firm basis for predicting base-wide water use. Where water meters had been installed, values were recorded for various family quarters; troop quarters; industrial, commercial, and administrative uses; irrigation; and recreational uses. These meters were the basis for estimating or extrapolating water use over an entire base.

[2] J. E. Matherly, et al., Water Usage Profile Fort Carson, CO, Interim Report N-34/ADA053227 (CERL, 1978).

3 CURRENT ARMY WATER SUPPLY PLANNING AND MOBILIZATION

Because water supply for mobilization is so important, CERL analyzed current water supply planning procedures in the context of mobilization. TM 5-813-1[3] summarizes the procedures the Army uses to design water supply and distribution systems. Briefly, an effective population is computed based on an installation's military, military-dependent, and civilian populations. This effective population is then multiplied by a multi-purpose capacity factor. The product is a design population which is used to determine the required capacity of the supply works, supply lines, treatment works, principal feeder mains, and storage reservoirs. The design population is the effective population multiplied by a capacity factor. The capacity factor is a means of providing an allowance for population increase. The required daily demand is the product of the design population and the per capita water allowance, plus any special industrial requirements and irrigation demands. Peak domestic demand is considered to be the greater of:

1. 2.5 times the daily average domestic requirements, or

2. The fire flow, plus 50 percent of the daily average domestic demand.

The capacity factor is very important, and is defined in TM 5-813-1 as follows:

> The capacity factor is the multiplier applied to the effective population figure to provide an allowance for reasonable population increase, variations in water demand, uncertainties as to actual water requirements, and for unusual peak demands whose magnitude cannot be accurately estimated in advance. The capacity factor varies inversely with the magnitude of the population in the water service area.

The capacity factors taken from TM 5-813-1 are given in Table 2.

Capacity factors are not applied to sizing distribution mains serving areas which are already fully developed or for fire flows, irrigation requirements, or industrial demands. A capacity factor would therefore increase cost.

The issues of capacity factor and per capita water allowance are related, since one function of the capacity factor is to compensate for "uncertainties as to actual water requirements." Both issues will be discussed together in the following section.

Relevant Considerations for Using Capacity Factor

A capacity factor, by definition in TM 5-813-1, could be used "to provide an allowance for reasonable population increase." It is accepted engineering practice to provide for a population increase when designing water and sewage works and sizing water distribution and sewage collection networks. The

[3] Water Supply Sources and General Considerations, Technical Manual (TM) 5-813-1 (Department of the Army, 1979).

Table 2

Capacity Factors

Effective Population	Capacity Factor
5,000 or less	1.50
10,000	1.25
20,000	1.15
30,000	1.10
40,000	1.05
50,000 or more	1.00

excess capacities to be provided are based on projected population growth during the service life of the facilities. These projections are normally arithmetic, geometric, or logistic extrapolations of previously observed growth patterns. They are valid only if the past trends on which they are based continue uninterrupted.

Mobilization would be a sudden break in an installation's history. Its population and mission would change suddenly. Appropriate allowances for future population increases could not be estimated by analyzing the installation's pre-mobilization experience.

It is therefore not possible to assess the use of a capacity factor as an allowance for future growth only on the basis of engineering considerations. Since there may be unforeseen demands at an installation, it will be to the Army's advantage to have the necessary utilities already available. The expense of providing excess capacity would purchase a flexibility whose value could be assessed only by mobilization planners. The planners would analyze the nature and likelihood of possible changes at installations of various sizes; they might then conclude that smaller installations would be disproportionately affected, and might reasonably specify the use of a capacity factor of the type now used.

According to TM 5-813-1, another possible role for a capacity factor is to provide for "unusual peak demands whose magnitude cannot be accurately estimated in advance." The Gifft equation is commonly used to predict the ratio of maximum to average sewage flows (Q) as a function of the population served by a sewerage system.[4]

$$Q_{max}/Q_{ave} = (5.0)\ P - .166 \qquad \text{[Eq 1]}$$

where P = population in thousands.

[4] H. M. Gifft, "Estimating Variations in Domestic Sewage Flows," Water Works and Sewerage, No. 92, (1945), p 175.

This relationship is a consequence of the damping effects of sewerage systems on the variability of their discharges. This damping is due to the steady seepage of groundwater into sewers, to the storages present in those areas of the network which have open channel flow, and to the long times of concentration which occur in large sewerage systems.[5] The Army's capacity factors have almost exactly the same relationship to population as that given by Eq 1 if that equation is scaled to equal 1.00 at a population of 50,000 (see Table 3).

Current Army practice requires the use of the same capacity factors for water supply and for wastewater treatment systems. The capacity factor may have originally been developed from wastewater treatment practice[6] and then extended to water supply design. If capacity factors were meant only to accommodate "unusual peak demands whose magnitude cannot be estimated in advance," there would be no reason for making the water supply and wastewater treatment factors equal. Although leakage from distribution systems and seepage into sewers are somewhat analogous in their effects on variability, no open channel flow occurs in a water distribution system.

The use of the capacity factor in water distribution system design probably serves a useful purpose in accommodating peak demands. The peak domestic demand to be used in water system design was defined on p 4 of TM 5-813-1, to be the greater of (1) 2.5 times the daily average domestic requirements, or (2) the fire flow, plus 50 percent of the daily average domestic demand. These criteria are the same for installations of any size. However, it is known that the ratio of peak to average water demands is greater in smaller than in larger communities.[7]

Table 3

Comparison of the Gifft Relationship and the Army Capacity Factors

Population	Gifft	Army Capacity Factors
5,000	1.47	1.50
10,000	1.31	1.25
20,000	1.16	1.15
30,000	1.09	1.10
40,000	1.04	1.05
50,000	1.00	1.00

[5] Fair, Geyer, and Okun, Water Supply and Wastewater Removal (John Wiley & Sons, 1966).
[6] S. A. Greeley and E. S. Chase, "Sanitation Facilities for Military Posts," Civil Engineering 12(7) (July 1942), p 359.
[7] Water Supply and Wastewater Removal.

Data compiled by Seidel and Cleasby[8] provide an extensive base for evaluating the average degree of variation in demand for typical American cities. They analyzed operational data from 1256 utilities representing more than 75 percent of the U.S. population and showed variation in demand as a function of population and volume. Thus, for example, while the maximum hourly demand for all cities averaged 2.83 times the average daily rate of flow, the mean for the largest volume group was 2.55 and that for the smallest group was 3.55. The largest value recorded for any particular city was 7.26.[9]

The inverse correlation between total demand and demand variation may not be valid when small populations of modest users of water and larger numbers of extravagant users of water are compared. This was shown in the work of Linaweaver and Geyer,[10] who found that peaking factors were higher in subdivisions containing homes of higher value. Similarly, Hughes[11] indicated that peak demand/average demand ratios were higher when average per capita consumption was high. Both these studies showed that lawn sprinkling has a dramatic effect on peak flows. If one assumes that significant irrigation would not be practiced in mobilization camps, this might make typical peaking factors a bit conservative.

Depending on the specific nature of the temporary Army facilities being considered, it might be prudent to compare flow rate variations at installations, rather that at municipalities. Searcy and Furman[12] tabulated flow factors for schools, motels, restaurants, shopping centers, and hospitals (the lowest hourly demand value was 1.9 times the average for hospitals, and the highest was 5.0 for elementary or junior high schools). The American Society of Civil Engineers (ASCE) Urban Resources Research Program has listed[13] expected flow rate variations for many types of commercial and institutional water uses. For example, the peak hour factor for high-rise apartments (2.64) or for colleges with students in residence (1.8) might provide a useful standard against which the anticipated nature of the Army installation can be compared.

Another approach for estimating peak loading factors has been to apply probabilistic techniques based on the number of fixture units installed. Depending on the nature of the Army installation involved, such an approach might be worthy of consideration. A recent discussion of a probabilistic

---

8 H. S. Seidel and J. L. Cleasby, "A Statistical Analysis of Water Works Data for 1960," Journal American Water Works Association, Vol 58 (1966), pp 1507-1527.

9 Jan Kmenta, Elements of Econometrics (McMillan Co., 1971).

10 F. P. Linaweaver and J. C. Geyer, "Use of Peak Demands in Determination of Residential Rates," Journal American Water Works Association, 56 (1964), pp 403-410.

11 R. D. Hansen, H. H. Fullerton, and T. C. Hughes, "Municipal Water Use," Utah Science, Vol 40, No. 2 (June 1979), pp 51-53.

12 P. E. Searcy and T. deS. Furman, "Water Consumption by Institutions," Journal American Water Works Association, 53 (1961), pp 1111-1119.

13 "Commercial Water Use," Urban Water Resources Research Program, Technical Memorandum No. 27 (American Society of Civil Engineers, 1975).

14 Wen-Yung W. Chan and L. K. Wang, "Re-evaluating Hunter's Model for Residential Water Demand," Journal American Water Works Association, 72 (1980), pp 446-449.

model has been presented by Chan and Wang.[14] Wolff[15] has presented another source of information on peak demand estimates based on the number of installed fixture units and variation in demand of water use in commercial installations. The use of a 2.5 multiplier with a design population calculated using the Army capacity factors is equivalent to using peak domestic demand factors which vary with population, as shown in Table 4. The use of such a population-dependent peak demand multiplier is consistent with the experience of small municipalities which Army installations resemble in many ways.

A third role for a capacity factor is to allow for "variations in water demand." Those variations which occur within an installation are discussed in the previous section on peak flow accommodation. There is also considerable variation in per capita water demand among different installations. The Army's experience in World War II suggested that per capita demand was inversely related to troop concentration. Greely and Chase[16] discussed this experience in a 1942 Civil Engineering article, from which Figure 3 was taken.

CERL performed an independent analysis of Greeley's and Chase's data which produced the following results:

1. Using all 24 observations, from Figure 3,

$$\underset{\text{(gpcd)}}{\text{per capita usage}} = 136.6 - 1.25 \underset{\text{(thousands)}}{\text{troop concentration}}$$

$r^2 = .316$ mean value of gpcd = 115.17

variable	coef	std err	t-stat	prob coef=0	mean
constant	136.628	6.72198	20.325	.00000	1.0000
concentration	-1.24471	.356749	-3.489	.00208	17.242

Table 4

Equivalent Peak Domestic Demand Multipliers

Population	Equivalent Multiplier
5,000	3.75
10,000	3.13
20,000	2.88
30,000	2.75
40,000	2.63
50,000	2.50

[15] J. B. Wolff, "Peak Demands in Residential Areas," Journal American Water Works Association, 53 (1961), pp 1251-1260.
[16] Greeley and Chase.

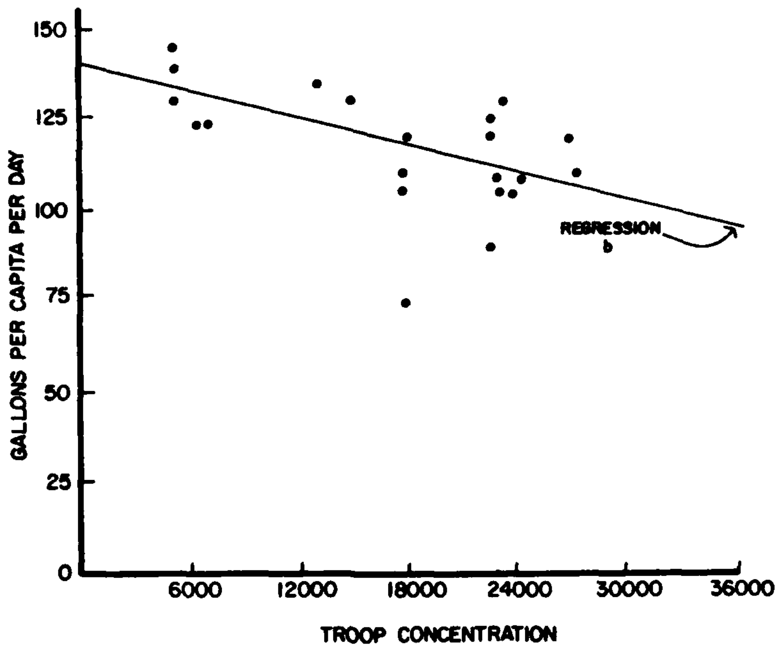


Figure 3. Relationship between per capita water usage and troop concentration in World War II (From S. A. Greeley and E. S. Chase, "Sanitation Facilities for Military Posts," Civil Engineering, 12 (7) (July 1942), p 359.)

2. Omitting the observation of 18,000 troops using only 71 gpcd as a possible outlier:

$r^2 = .47$ Mean value of gpcd = 117.09

variable	coef	std err	t-stat	prob coef=0	mean
constant	138.082	4.96367	27.819	.00000	1.0000
concentration	-1.22003	.262933	-4.640	.00014	17.209

There is a highly significant variation of per capita demand with troop concentration. The existence of this relationship could reasonably be taken into account by using a capacity factor. If regression 2 above were used as the basis, the factors might be as shown in Table 5.

CERL obtained water production and population served data from the 1980 Facility Engineer's Annual Summary of Operations to determine whether the relationships observed during World War II are still accurate today. The next section presents this analysis and describes an attempt to derive a gallons per capita per day recommendation for mobilization, based on measured water use at Army installations.

Table 5

Capacity Factors Assuming an Inverse Relationship Between Troop Concentration and Per Capita Demand

Population	Army Capacity Factor	From Regression
5,000	1.5	1.71
10,000	1.25	1.63
20,000	1.15	1.47
30,000	1.10	1.32
40,000	1.05	1.16
50,000	1.00	1.00

Current Gross Per Capita Use

CERL considered data from a variety of sources when developing recommendations for using the capacity factor and for adjusting the per capita water allotment for mobilization. The primary source was the FE Red Books[17] from 1968 through 1980. Since the water production/procurement and population data given in the Red Book are not always accurate for an installation, no recommendation depends on only one or even a few installations. Each is based on a statistical analysis of the reported production (or procurement) and population served values for a large number of representative Forces Command (FORSCOM) and Training and Doctrine Command (TRADOC) installations.

Effective population is currently defined as the sum of on-post military personnel and their on-post dependents, plus one third of the civilian workforce. It is unlikely that military personnel display the same per capita water use as their dependents. CERL's metering of civilian water use at Fort Carson has revealed that civilian per capita use at that post is more nearly one-ninth than one-third of 150 gpcd. It is important that the formula used to calculate effective population be nearly correct, especially where the makeup (proportion military, dependent, or civilian) of a group of installations varies greatly. Incorrectly weighting military, dependent, and civilian water demands introduces a spurious source of variation into per capita consumptions computed on the basis of effective populations. Per capita uses for each component of an installation's population should probably be developed separately and used in lieu of one overall factor applied to an artificial effective population. Although the procedure will be slightly more complex, better demand predictions can be made.

The population values given in the "Army Times" 1980 directory issue were analyzed to try to determine whether the formula used to compute effective population was correct. However, the analysis was inconclusive, because the "Army Times" does not distinguish between on- and off-post populations. It was interesting to note that the "Army Times" military population figures were

[17] Facilities Engineering Annual Summary of Operations (published annually by the Office of the Chief of Engineers).

a better predictor of installation water use than were the Red Book effective populations; however, the difference was not great.

It seemed possible that FORSCOM and TRADOC installations might have different water consumption patterns, since their missions are so different. Therefore, installations from each MACOM were at first analyzed separately. Initially, all the installations in the Red Book were included. After examination, however, some installation data were excluded from the analysis because they were so unusual. An example is Fort McCoy, which apparently consumes nearly 1000 gal per capita per day (probably because of uncounted reservists).

Figure 4 gives the per capita water use at the 17 FORSCOM installations analyzed. Regressing per capita use on installation effective population yielded the following equation:

$$\underset{\text{(gpcd)}}{\text{per capita use}} = 120.5 - .068 \underset{\text{(thousands)}}{\text{effective population}} \qquad \text{[Eq 2]}$$

r^2 = .005 mean value of gpcd = 122.51

variable	coef	std err	t-stat	prob coef=0	mean
constant	120.543	26.1141	4.616	.00034	1.0000
redbook	.689008e-01	.797201	.086	.93227	28.592

The regression coefficient is not significantly different from zero; therefore, the best predictor for per capita water consumption at FORSCOM installations is simply the average of these observations -- 123 gpcd. There is noticeably more variation at small than at large installations.

Figure 5 presents the corresponding data for TRADOC. The regression analysis produced the following equation:

$$\underset{\text{(gpcd)}}{\text{per capita use}} = 128.4 + .66 \underset{\text{(thousands)}}{\text{effective population}} \qquad \text{[Eq 3]}$$

r^2 = .018 mean value of gpcd = 141.74

variable	coef	std err	t-stat	prob coef=0	mean
constant	128.372	28.2833	4.539	.00046	1.0000
redbook	.661784	1.23525	.536	.60054	20.202

This regression coefficient is not significantly different from zero. The best predictor of per capita water consumption at TRADOC installations is the average of the TRADOC observations -- 142 gpcd. The variability of the individual observations varied inversely with effective population size, just as it did for FORSCOM. While per capita consumptions were independent of

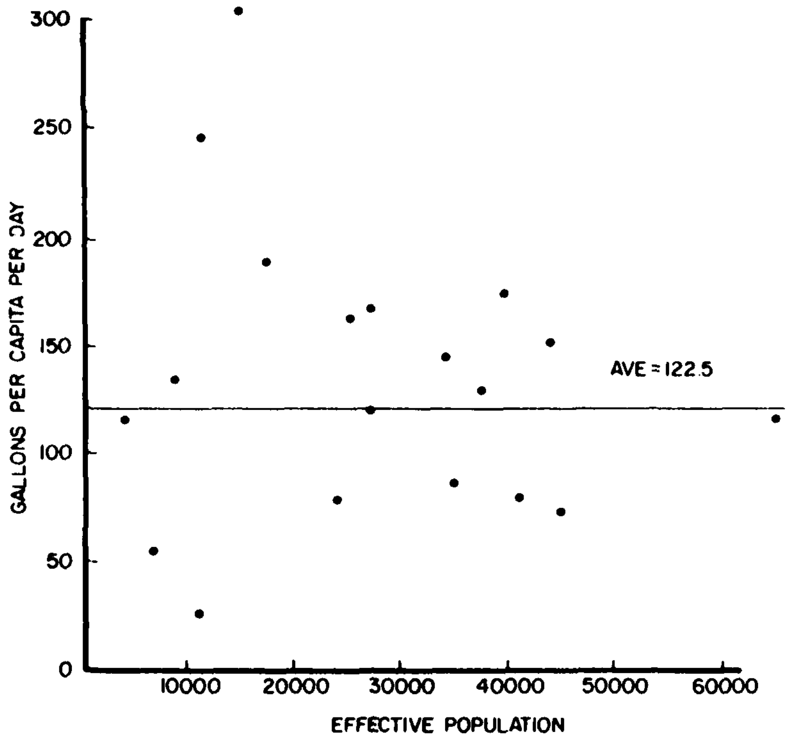


Figure 4. Per capita water consumption for 17 representative FORSCOM installations - 1980.

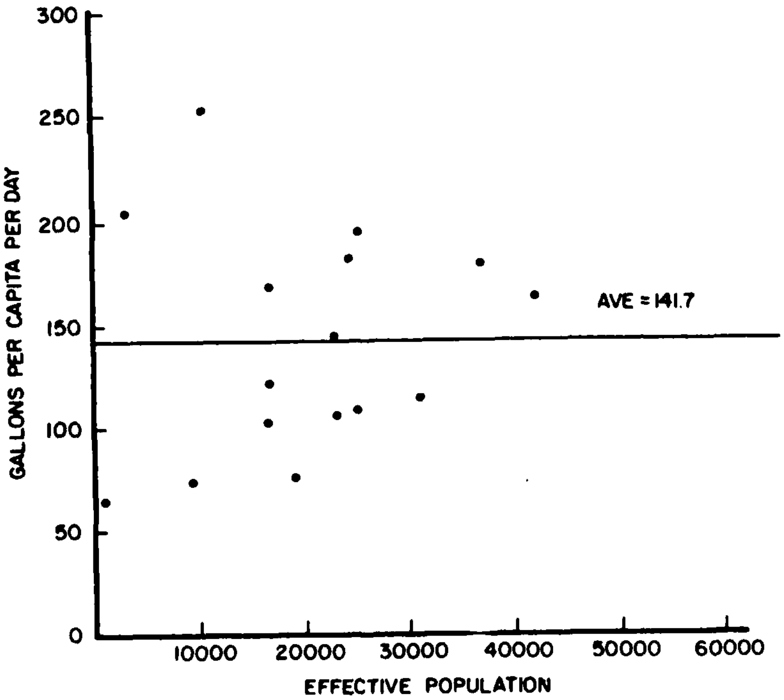


Figure 5. Per capita water consumption for 16 representative TRADOC installation - 1980.

effective population at both MACOMs, there was an apparent difference in average per capita consumption between them: 123 gpcd for FORSCOM and 142 gpcd for TRADOC. A statistical analysis of the combined data was performed to determine if this difference was real. A dummy variable was created whose value was one for FORSCOM and zero for TRADOC. Per capita use values from both MACOMs were then regressed against effective population and the product of effective population and the dummy variable. The results were:

$r^2 = .016$ mean value of gpcd = 136.93

variable	coef	std err	t-stat	prob coef=0	mean
constant	137.967	21.4960	6.418	.00000	1.0000
redbook	.292069	1.06058	.275	.78485	24.231
iredbook	-.55124	.835605	-.660	.51432	14.724

Neither the effective population coefficient nor the interaction term coefficient (which would have differentiated the MACOMs) was significantly different from zero. The mean value of 137 gpcd is the best predictor of water use at either MACOM. The standard deviation of the pooled observations was 60 gpcd; the standard error of the mean was 10.33 gpcd.

Effective population and troop concentration are probably not exactly equivalent (Greeley and Chase did not define troop concentration). However, the two should be sufficiently correlated that per capita consumption in the 1980 data would be negatively correlated with effective population if the World War II patterns (Figure 3) were still valid today. CERL's analysis indicates that the relationships observed during World War II are no longer valid. During World War I, the Army observed a sewage flow of about 55 gpcd.[18] World War II planners allowed for changes by raising the design sewage contribution to 70 gpcd. In practice, an average per capita flow of 97.5 gpcd was observed, with individual posts such as Camp Forest and Camp Blanding receiving return flows of 115 gpcd.[19]

The average per capita water consumption calculated from the Red Book analysis was 136.93 gpcd, with a standard error of the mean of 10.3 gpcd. To be 90 percent certain that the real average value is not higher than the recommendation, 1.28 should be added to the average use for standard error. This procedure yields a planning factor of 150 gpcd -- the same as currently used.

If this allowance alone were used (no capacity factor) to size water systems, a large percentage of the smaller installations would be grossly undersupplied. If the standard deviation of the total set of observations were used to provide a comparable 90 percent assurance, a 220 gpcd recommendation would be needed. This would be wastefully conservative for large installations. Figure 6 presents the combined data for TRADOC and FORSCOM; the two candidate recommendations are drawn in. The line for a base 150 gpcd in combination with the current capacity factor is also presented. This option

[18]Greeley and Chase.
[19]Greeley and Chase.

would under-supply about one third of the larger installations (24,000 to 44,000 people).

When the regression analyses were performed on the Red Book data, researchers observed that the data were heteroskedastic for both MACOMs; i.e., the variability of the data was not random, but decreased in the direction of increasing effective population. A special statistical analysis was performed which accounted explicitly for this heteroskedasticity.[20] Figure 7 shows the mean (now dependent on effective population, though still not significantly) and the 90 percent upper confidence limit superimposed on the combined data. The confidence limit is actually a very flat hyperbola-like curve, but in the region of interest, it is well approximated by the straight line shown.

Table 6 presents capacity factors derived from this confidence limit. They assume a per capita allowance of 158 gpcd. A comparison of Figures 6 and 7 shows that the confidence limit based capacity factors are a much better hedge against uncertainty than are the present capacity factors which assume 150 gpcd. Figure 8 presents the results of applying the current capacity factors but allowing 170 gpcd. This alternative also hedges well against

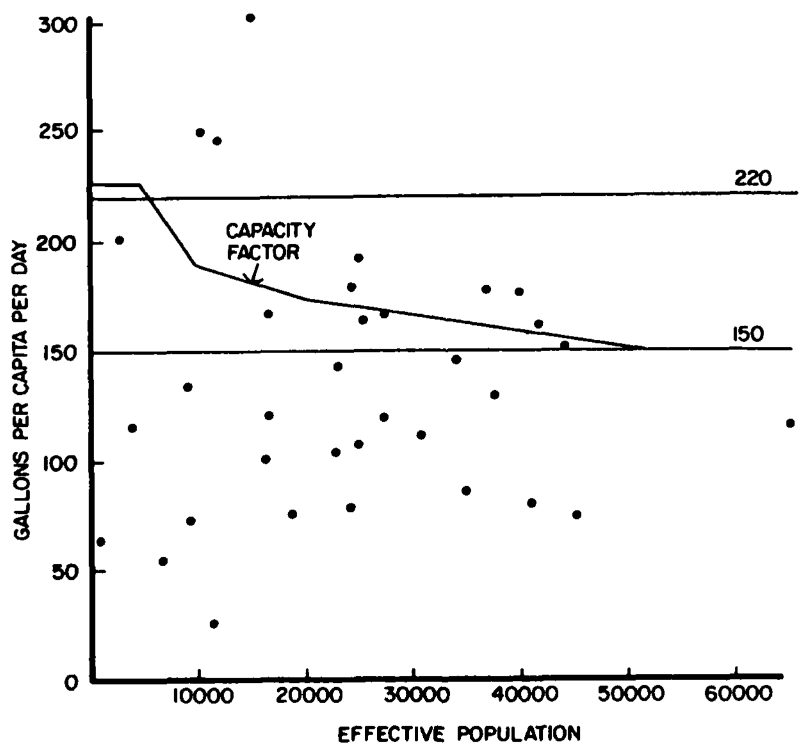


Figure 6. Combined FORSCOM and TRADOC per capita water use observations.

[20] J. Girand, "Army Camp Water Supply Systems," Civil Engineering, 13(5) (May 1943), p 219.

Effective Population	Capacity Factor
5,000 or less	1.63
10,000	1.56
20,000	1.41
30,000	1.27
40,000	1.14
50,000 or more	1.00

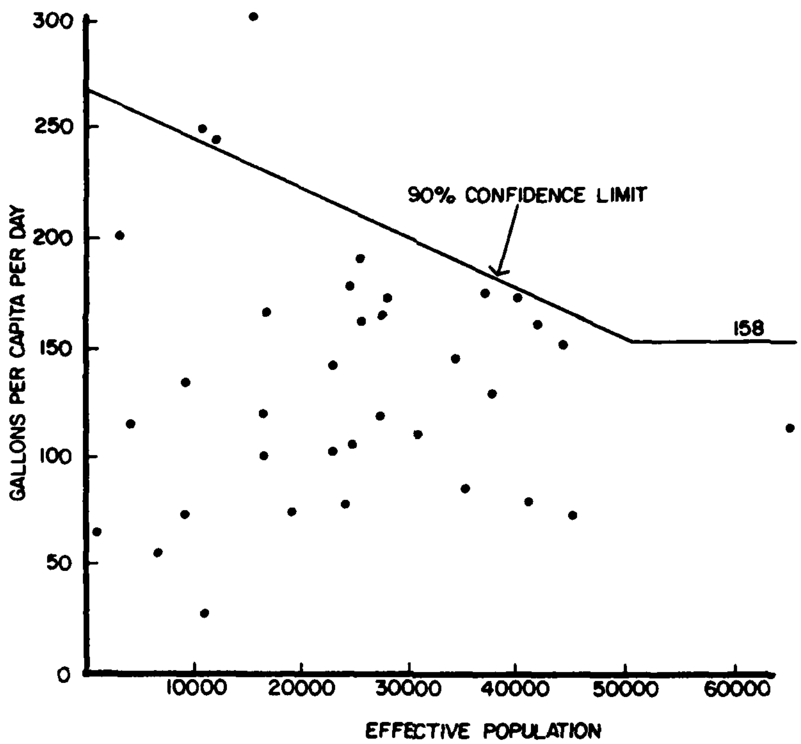


Figure 7. Derivation of a capacity factor from the observed variability.

uncertainty (although it may be unnecessarily conservative for the largest installations).

Either the factors from Table 6 on a 158 gpcd base or the current factors on a 170 gpcd base should provide adequate supplies for mobilization bases; however, the current *design procedure is probably not conservative* enough. During World War II, the Army underestimated both water consumption and sewage production,[21] so the knowledge gained from this should be used accordingly.

To effectively analyze an individual installation's mobilization water requirements requires specific information about the water needs and uses at that installation. Chapter 4 discusses the concepts of metering and leak detection, which installations can use to determine the rate of use and total use of their water-consuming activities. Chapters 5 through 8 provide specific information on the water needs of four of the installations surveyed by CERL: Forts Carson, Lewis, Bliss, and Bragg. This type of information will be useful in analyzing mobilization water requirements for these installations.

[21]Greeley and Chase.

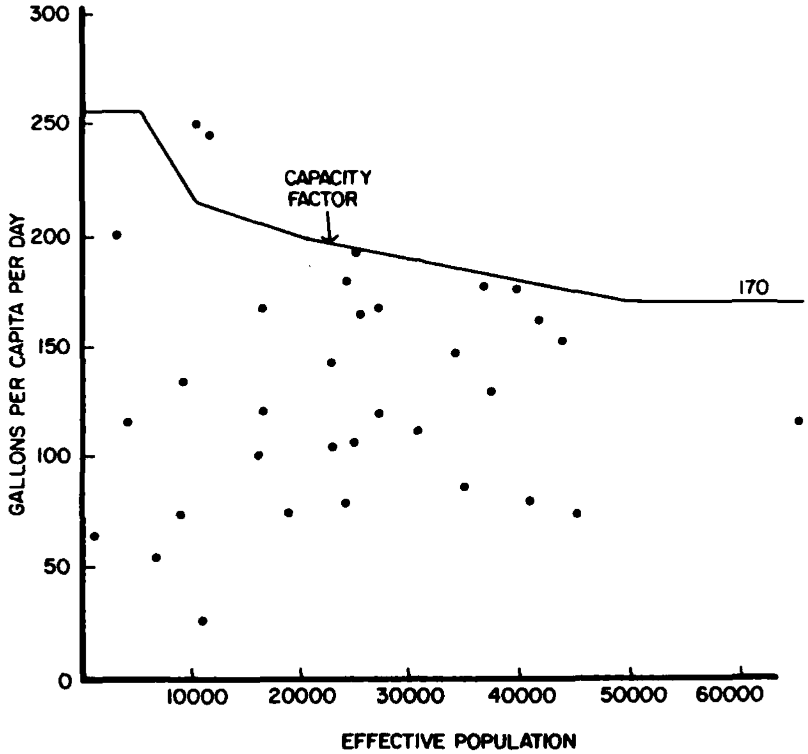


Figure 8. Use of the current capacity factor with a 170 gpcd basic allotment.

Table 6

Confidence Limit Based Capacity Factors

Effective Population	Capacity Factor
5,000 or less	1.63
10,000	1.56
20,000	1.41
30,000	1.27
40,000	1.14
50,000 or more	1.00

4 METERING AND LEAK DETECTION

Determining water use distribution on any military installation requires a rational method of analysis. Metering is the most accurate procedure for determining rate of use and total use of any water-consuming activity. Various types of water meters have been used for many years throughout the world. In the United States, most municipalities meter both residential and industrial users; however, military installations do not meter residences or most on-post facilities, since it is not Army policy to charge residents for water.

Installations have master meters at their treatment plants which measure the amount of water treated and entered into the distribution system. To maintain reliable records, care must be taken to insure that the base master meters are calibrated regularly and accurately. However, some installations meter and charge on-post facilities which are supplemental to the primary mission. Others meter some of the major water users on base which are not charged for water.

Benefits of Metering

The following are some of the primary benefits of metering: provision of an equitable allocation of costs (i.e., consumers pay for what they use); identification of demand trends over time; enhancement of the ability to detect serious leaks; calculation of operations efficiency; provision of consumption information; and conservation of water (i.e., when people pay for their water, there is less waste). The lower consumption may also save the expense of new construction and source development. The major benefits of metering to the Army includes characterizing water use for different activities to set baseline figures for additional planning or conservation efforts, new construction, and indication of leaks in the system.

Metering will provide opportunities for saving water because less water will have to be produced; in turn, expenses will be reduced, there will be less sewage which requires treatment, and irrigation will be less intensive. Baseline data is valuable for base expansion and/or mobilization. Consumption reports on various Army activities would identify conservation opportunities and establish criteria for further base expansion.

Determining whether a metering program is beneficial for an Army installation in terms of cost and effort relies on (1) accountability of water, and (2) baseline data for planning purposes. Accountability involves understanding how much and where water is consumed. If consumption increases suddenly, metering can determine fairly easily whether it is a consumptive change or a distribution system leak. Also, when planning changes or reacting to crises, an accounting of water use makes analyses and decision-making easier.

Criteria for Installing Meters

Once an installation decides to undertake a metering program of any magnitude, some decisions must be made. Should the metering be a one-time approach, or is a permanently installed meter desirable? If temporary metering is desired, non-invasive ultrasonic flow meters can be attached to pipes in a distribution system without interrupting flow. More permanent installations usually require a meter in the pipe or a bypass plus appropriate valving. In deciding where to locate water meters, representative activities can be selected that will adequately indicate water use distribution, rather than metering the whole installation.

The number of representative facilities to be selected for metering can be determined on the basis of pilot metering data. The number of sites metered and available resources must be balanced. If more sites are metered, the data will be more accurate. For example, the water at Fort Carson, CO, costs $760 per million gallons; therefore, a savings of 5 or 10 percent in base water consumption would save the installation $46,000 or $92,000, respectively, per year. Several residences or groups of residences should be metered to calculate average family housing use. Several barracks and messhalls should be metered. It would be very helpful to know the number of people occupying each building and to know what percentage of residents maintains off-post apartments. A figure for per capita use in the administrative or office building category can be provided if a few of them are metered and if office population is known. Commercial ventures should be metered, since they pay directly for their water. Other representative users, such as schools, clubs, or bowling alleys, should also be metered. On many installations, irrigation is often a large water consumer. Golf courses, cemeteries, and representative sections of parade grounds, parks, and athletic fields should be metered to estimate water use in nonfamily housing areas. Family housing irrigation use can be roughly estimated by comparing the seasonal difference in water consumption. In some regions, industrial use may be a large consumer, so metering of laundries, some vehicle washracks, boiler plants, and other large users is suggested. Hospitals are also large water consumers, and should be metered. Water consumed in various activities may be estimated by knowing the representative users, their numbers, the base population of the various user categories, and acreage covered by irrigation. This baseline data may be used for planning purposes as well as determining whether there are any major leaks.

Types of Meters

A variety of water meters are in use today.[22] They may be actuated by nutating disk, oscillating piston, or rotor. The first two have been widely used in the United States, with rotor models becoming common recently. Nutating disk meters have a hard rubber or polymeric disk which oscillates in guides, rotating one time for each filling and emptying of the meter chambers.

[22] N. P. Cheremisinoff, and R. A. Niles, "A Survey of Fluid Flow Measurement Techniques and Fundamentals," Water and Sewage Works (December 1975), pp 74-78; J. P. Wolfner, "Flow Metering in Water Works," Journal American Water Works Association (February 1971), pp 117-122; H. E. Snider, "The Meter Revolution," Journal American Water Works Association (February 1977), pp 66-67; L. E. Orr, V. A. Enna, and M. C. Miller, "Analysis of a Water-Meter Replacement Program," Journal American Water Works Association (February 1977), pp 68-71; E. Seruga, "Sizing and Selecting Modern Water Meters," Water/Engineering and Management (January 1982), pp 40-42.

Piston meters are positive displacement meters which measure filling and emptying of a chamber of known volume. Rotor meters are flow meters which measure flow velocity, inferring volume from velocity and meter dimensions. The positive displacement or nutating disk meters have been used mostly in residences or in other applications where there are long periods when water is not used. Flow meters and propeller meters are normally used where a large volume is used. Compound meters are a combination of the positive-displacement and current-type meters. They have hydraulically activated automatic valving which transfers flow to the appropriate meter section to account for rapid changes in demand between high and low flows. New types of high-speed horizontal turbine meters developed during the 1970s have improved operations. In effect, a smaller turbine meter can replace a larger one of the old style. The American Water Works Association has published standards for water meters and information on sizing service lines and meters.[23] Table 7[24] presents recommended uses for meters by type classification.

Meters are generally made of bronze, although the insides of current models are extensively plastic. All-plastic meters are also on the market.[25]

Sizing meters is an important step in the installation process.[26] Oversized meters or large, high-capacity meters in low use often tend to become inoperable due to turbine, disc, or piston binding, which results in frequent service calls. Undersized meters or inadequate services will cause complaints, excessive wear on the meter, and high maintenance costs. Peak demand is usually the basis for meter installation.

Many consumers or classes of consumers have individual use characteristics which have been determined and are readily available in textbooks or AWWA publications.[27] Historical data (i.e., comparable civilian activities which have been metered) are often used to size meters. Also used often are rule-of-thumb judgments by experienced installers, plumbers, or engineers. Portable metering equipment is also available for determining use patterns, including a recording device to show peaks during use.

Oversizing has been a common practice, and in many cases, meter size could have been reduced one size without harming service. Selection of type and size of meter should be based only on the flow requirement and type of use. Design procedures for meter size selection, including necessary tables[28] are available from the AWWA.

---

[23]Sizing Water Service Lines and Meters, AWWA Manual M22 (American Water Association, 1975).

[24]E. Seruga.

[25]W. V. Lacina and J. B. Coel, "Plastic Water Meters," Journal American Water Works Association (May 1976), pp 246-247.

[26]E. Seruga; AWWA Manual.

[27]AWWA, 1975.

[28]AWWA Manual.

Table 7

Recommended Uses for Meters by Type Classification
(From E. Seruga, "Sizing and Selecting Modern Water Meters,"
Water/Engineering and Management [January 1982].)

Meter Type, Size Positive Displacement	Recommended Applications
5/8 in.	Residences, small apartments, small businesses Demand flow rates: 1/8 to 29 gpm Maximum continuous demand to 10 gpm.
3/4 in.	Large residences, small to medium apartments Demand flow rates: 1/4 to 30 gpm Maximum continuous demand to 15 gpm.
1 in.	Medium apartments, beauty parlors, barber shops, small motels, filling stations, small businesses, industrial processes Demand flow rates: 3/8 to 50 gpm Maximum continuous demand to 25 gpm
1 1/2 in.	Medium motels, hotels, large apartments, small industry, small processing plants. Demand flow rates: 5/8 to 100 gpm Maximum continuous demand to 50 gpm
2 in.	Larger hotels, motels, apartment complexes, industrial plants, processing plants. Demand flow rates: 1 1/4 to 160 gpm Maximum continuous demand to 80 gpm.
Class II -- Turbine	
2 in.	Medium to large hotels, motels, large apartment complexes, industrial plants, processing plants, irrigation. Demand flow rates: 3 to 200 gpm Maximum continuous demand -- 160 gpm.
3 in.	Large hotels, motels, industrial plants, processing plants, irrigation. Demand flow rates: 4.3 to 450 gpm Maximum continuous demand -- 350 gpm
4 in.	Large industrial and processing plants, irrigation, refineries, petrochemicals, pump discharge. Demand flow rates: 25 to 2500 gpm Maximum continuous demand -- 1000 gpm.

Table 7 (Cont'd)

Meter Type, Size Positive Displacement	Recommended Applications
6 in.	Large industrial manufacturing and processing plants, irrigation, pump discharge. Demand flow rates: 25 to 2500 gpm Maximum continuous demand -- 2000 gpm.
Class I -- Turbine Meters*	
8 in.	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 140 to 1800 gpm Maximum continuous demand -- 900 gpm.
10 in.	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 225 to 2900 gpm Maximum continuous demand to 1450 gpm.
12 in.	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 400 to 4300 gpm Maximum continuous demand to 2150 gpm.
Compound Meters (New High- Velocity Styles)	Medium motels, hotels; special customers having high and low demand; schools, public buildings, large apartment and condominium complexes, hospitals.
2 in.	Demand flow rates: 1/4 to 160 gpm Maximum continuous demand to 160 gpm.
3 in.	Demand flow rates: 1/2 to 350 gpm Maximum continuous demand to 350 gpm.
4 in.	Demand flow rates: 3/4 to 1000 gpm Maximum continuous demand to 1000 gpm.
Compound Meters (Older Styles)	
6 in.	Demand flow rates: 1 1/2 to 1000 gpm Maximum continuous demand to 500 gpm.
8 in.	Demand flow rates: 2 to 1600 gpm Maximum continuous demand to 800 gpm.
10 in.	Demand flow rates: 4 to 2300 gpm Maximum continuous demand to 1150 gpm.

*Class I turbines below 8 in. not included because of the higher performance of Class II models.

Meter Selection

The selection and purchase of water meters should be based on three factors: (1) cost to purchase it, (2) cost of repair during service life, and (3) effective service life. Meter selection is an important step. Magnetic-drive positive displacement meters with remote read are the meters used by most utilities, and are the direction the industry is moving in. The remote reads with the attendant generator make the meter easy to read. The meters are bronze with plastic insides. Today's water meters are cheaper and more accurate than in the past and are constantly improving. Experimental work has used phone lines and cable television to read meters directly by a computer, but commercial application is several years away.

Problems

Metering poses few problems. Major obstacles are the costs of installation, especially if excavation is needed; meter costs (large meters are expensive); and increased costs due to a possible need for valves and bypasses. Labor costs may be another concern in an application. Someone must read the meters, people may have to be pulled from their regular duties to do any needed repair work. Meter installation may be hazardous. Sometimes water lines are improperly used for grounding; if a great deal of electric current is being conducted, they may shock the installer, so a copper jumper around the meter may be needed.

Installation

Meter installation may either be done in-house or contracted out. Residential metering is relatively simple and has sometimes even been done by residents.[29] The preferred installation method is by the Directorate of Engineering and Housing (DEH) since, for optimal efficiency, they would own and maintain the water meter. In rare instances, the consumers maintain and purchase the meter, which results in less maintenance. To avoid health hazards when meters are installed, DEH water personnel or qualified plumbers should do the work. Appropriately, in many municipalities, it is illegal for anyone other than a licensed plumber to put in a meter. If an Army installation purchases water from a nearby city or town which does metering, contracting may provide a mutually beneficial metering solution. If a contractor is used, the meter installation details will have to be negotiated; for instance, (1) the contractor could do everything, (2) just install the meters and do excavation work, or (3) install only meters.

Leak Detection

With an adequate database established, it is possible to determine percentages of water in various categories in an approximate pattern. Water that is unaccounted for should be of a reasonably low percentage. To a small extent, there will be unavoidable leakage in the mains and other lines;

[29] "Iowa Townspeople Install Their Own Meters," Water and Sewage Works (March 1976), pp 60-61.

however, water main loss usually ranges from 2 to 8 gal per capita per day, which is insignificant when considering that a dripping faucet loses 12 gal per day and a leaking toilet may lose 60 gal per day. Estimates of unavoidable water loss are 1500 to 3000 gal per day per mile of main, depending on age and type of pipe. The American Water Works Association (AWWA) for municipalities[30] recommends that a 1 percent loss be estimated for firefighting, street flushing, or other incidental uses.

Water waste surveys and leak detection programs are basic parts of a water utility's operations and maintenance schedule. Undetected leaks have been reported to waste from less than one-tenth to as much as one-third of the water treated at some systems. Large amounts of unaccounted water indicate a need for a water waste survey, especially if losses have suddenly increased. Waste surveys or leak detection programs may indicate undiscovered breaks or blown joints in water mains, unauthorized users, or wasteful consumption. Due primarily to the lack of water meters, many Army installations lack the basis for knowing if there are major leaks in their systems. As a result, delay in maintenance and/or replacement programs can cost thousands of dollars in emergency overtime and replacement of lost water.

Benefits of a Leak Detection Program

A leak detection program has several benefits:[31]

1. Water is saved, because unnecessary waste is eliminated.

2. Energy is saved by reducing the energy required for treatment and distribution of the water supply.

3. Money is saved (e.g., fewer chemicals are needed); eventually the short-term expense for the program will be justified.

4. Capacity is saved, in that a larger population can be served without major modifications to the system.

5. Capital expense is saved or deferred because the larger available water supply may ease expansion problems or defer planned construction activities.

6. There will be greater knowledge of the distribution system, which will improve operation and maintenance.

[30] W. D. Hudson, "Increasing Water System Efficiency Through Control of Unaccounted for Water," Journal American Water Works Association (July 1978), pp 362-365.

[31] E. E. Moyer, J. W. Male, I. C. Moore and J. G. Hock, "The Economics of Leak Detection and Repair -- A Case Study," Journal American Water Works Association, Vol 75, No. 1 (January 1983) pp 28-34; F. S. Brainard, "Leakage Problems and the Benefits of Leak Detection Programs," Journal American Water Works Association (February 1979), pp 64-65; W. J. Kingston, "A Do-It-Yourself Leak Survey Benefit-Cost Study," Journal American Water Works Association (February 1979), pp 70-72.

7. Property damage from leaks will be prevented, providing benefits in terms of reduced inconvenience, lawsuits, insurance claims, materials, energy, and public relations.

8. More accurate leak location will save in leak repair crew time.

9. There will be less wear on distribution system and pumping and treatment facilities.

10. Contamination risk will be reduced.

Beginning a Leak Detection Program

After a decision is made to set up a leak detection program, there are two paths to pursue: either train installation personnel, or hire a consultant. Often, a consulting firm can help begin a utility-operated program and train appropriate personnel. Individuals selected to operate the leak detection equipment should be experienced pipeline personnel. System records must be reviewed carefully before implementing any program; detailed drawings of up-to-date, accurate maps should be available which indicate all mains, valves, and intersections. Often, abandoned service lines or mains or missing stubs may cause a leakage problem. A review of leak records, pipeline corrosion records, and local soil conditions could indicate a starting point.

A water system is made up of distribution districts which are the major supply areas. The initial job of a water waste survey is to identify areas with major leakage. Once sections with abnormally high flow are determined, leak detection equipment can be used to locate the leak.

Equipment and Methods

Water waste surveys are usually done with pitometers placed in water mains where the flow is to be measured. Another way is to close all the valves on mains which lead into a district, and then supply water through a hose which connects two fire hydrants; a large water meter can be placed in the hose line. Closing valves on all but one of the mains entering a district and measuring flow at night, when domestic use is low, will indicate approximate locations of loss. A side benefit of pitometer use is that it determines the friction coefficients of large water mains, and indicates valves which should have been open, but were partially or fully closed.

Leaks are detected in varied ways. Sometimes, the leak just washes away everything nearby, thereby revealing its location. Often, the water comes to the surface, and sewers and culverts sould be examined for water which is entering through joints and fissures. Surface depressions or wet spots may indicate leaks; as may green grass in unwatered dry areas, melted snow in the winter, and flooded streets. Often, the water is observed quite far away from the actual leak.

Invariably, leaks are isolated using sonic techniques. High-pressure water being forced out through the leak loses energy to the pipe wall and surrounding soil. This energy produces sound waves which can be picked up by electronic transducers or simple mechanical devices. These waves are evaluated by an individual trained in leak detection to determine the leak's location and relative size.

There are three typical leak sounds.[32] One, in the 500 to 800 Hz range, usually begins as an orifice-pipe vibration phenomenon and is transmitted along the pipe wall, sometimes for considerable distance. This sound is identified by systematic testing of valves, hydrants, and curb valves, and will often locate potential leak areas.

The other leak sounds are in the 20 to 250 Hz range. The second sound is caused by the impact of water on the soil beside the leak, and the third, which resembles the sound of a fountain, is usually caused by water circulation in a soil cavity near the leak. The travel distance of these sounds is limited to the immediate area of the leak, making them important to pinpointing its location.

Other factors affecting leak sounds which should be considered include[33] pressure (15 psi is necessary), pipe size, and pipe material (metal conducts better than plastic, although sonic techniques can be used on any pipe or fittings), soil type, leak configuration, and background noise. For example, sand is a good conductor, but clay is poor. Concrete and asphalt provide good resonators, while sod insulates and muffles sounds.

Electronic amplification instruments which are now available can reduce background noise by electronic filters or by using limited-range microphone pickups. However, background noise cannot all be filtered out, since some noises have the same frequencies.

A leak survey has two phases: searching and pinpointing. Leakage areas are identified by listening at direct contact points such as hydrants, main line valves, or meters. Then the leak can be bracketed or pinpointed by several procedures. Large (greater than 12 in.) mains should receive surface tests, because the large mass of metal may diminish the vibration sound of the pipe. The pinpointing phase of the leak survey is the most difficult and requires a highly skilled operator. The operator should know pipe materials and all changes in the pipe, such as bends or reducers, from installation records and maps. Acoustic methods and equipment such as listening sticks, stethoscopes (aquaphones and geophones), and electric amplifiers using microphones and screening circuits are not always successful, and alternative methods of leak detection have been developed.[34]

Several types of tracer gases with various advantages and disadvantages are available. Compared with sonic surveys, they are very expensive and should only be considered when sonics are totally impractical. Four

---

[32] P. M. Heim, "Conducting a Leak Detection Search," Journal American Water Works Association (February 1979), pp 66-69.

[33] Heim; Moyer, et al; W. F. H. Gros, "Leak Detection Problems in Cold Weather Conditions," Journal American Water Works Association (January 1976), pp 8-9; J. E. Pilzer, "Leak Detection -- Case Histories," Journal American Water Works Association (November 1981), pp 565-567.

[34] Heim; E. S. Cole, "Methods of Leak Detection: An Overview," Journal American Water Works Association (February 1979), pp 73-75.

possibilities include: nitrous oxides with infrared detection; 10 percent helium, 90 percent air; methane-nitrogen; and methane-argon. All of these require special portable detection equipment.

Other methods include a correlation technique which removes interference when acoustic methods are used by taping numerous microphone pickups and using correlation equipment; pressure differential to establish gradients; vegetable dyes or salt solution tracers; and fluoride gaseous techniques.

Costs and Potential Savings

Surveys for performing a water waste audit in which consumption is compared with the master meter over a 24-hour period to discover and isolate large leaks range from $150 to $450 per mile. Initially, valving is used to isolate distribution networks into 15 to 20 miles of water main districts. Costs are a function of the complexity of the network. Sounding surveys to isolate the leaks cost about the same, and the price included engineering service. The client would put in the taps, do the excavation, and furnish transportation and labor assistance. All consultants can train installation personnel.

Installations which want to establish an in-house program would have the following costs. A crew of two would be required. At least one should be familiar with leak sounds; the other would be a helper to carry tools and act as flagman. A truck would be needed for transportation, and the leak detection equipment would be a few thousand dollars. Repair costs per leak were estimated at $250 in 1979.[35] A crew can probably cover 2 miles of water line per day, finding several small leaks per day and one main line leak per week. Other estimates show up to 8 miles per day per crew of two.

The benefits of water waste surveys include savings in water, chemicals, energy, potential water damage, deferred construction costs, and increased capacity. Financial savings are often considerable, since the discovery of one large leak may save many thousands of dollars. Kingston[36] has developed an easy-to-use method for computing the benefit-cost ratio.

One recent example[37] of the benefits of leak detection was the survey of a utility serving 50,000 people at about 10 mgd. Leak detection surveys were performed regularly every 2 years during a 6-year period. Numerous leaks were found in every survey, but the initial survey found a greater number of serious leaks than the other two. Over the 6-year period, about 2.8 billion gal of water were saved, worth more than $400,000 in 1980 dollars. Total leak detection and repair costs were $239,000, yielding a net benefit of $162,000. Breakdown of the expenses of the leak detection and repair program were: leak detection services (46.3 percent), labor (21.8 percent), percent overhead (16.7 percent), pavement (10.4 percent), and materials (4.8 percent). Analysis by the different types of leaks produced an average cost of $212 per leak with a benefit of $806 per leak, or a net gain of $594 each. Ignoring dry holes or leaks on other utilities, the average net benefits for different

[35] W. L. Kingston.
[36] W. L. Kingston.
[37] E. E. Moyer.

categories are: hydrant ($163), service-customer ($1078), service-utility ($631), and main $(2213). These benefits include water value saved plus power and chemical costs. In this example, only 0.5 percent of the total leaks found by sonic location were dry holes. Location prediction was: hydrant leaks -- 96.6 percent correctly located; customer service -- 86.8 percent; utility service -- 55.9 percent; and mains -- 84.5 percent. Pilzer, Sowby, Kingston, and Laverty[38] present many other case histories.

Each million gallons of water produced for power and chemical treatment by the Gary-Hobart Water Corporation of Gary, Indiana[39] had a 1979 value of $66.10. A leak of 1 gpm wastes 500,000 gal of water per year, costing them $33.00, and thus providing an incentive for leak detection. In another example, a small Wyoming town[40] without meters seemed to be using 1500 gal per person per day with less water pressure than in previous years. A 1 mgd leak was found in a transmission line which, when fixed, recovered 33 percent of the water supply and increased water pressure by 53 psi. Another 17 percent of the supply was being lost in the distribution system.

In a small Utah town,[41] a water survey using pitometers found a zone with 21 leaks in an old lead-joint line, losing 50 percent of the water supply. A crushed pipeline in another Utah town[42] was discharging water into an adjacent river. Repair of this leak saved one-fifth of the city's supply.

Some leaks[43] found in the Los Angeles area included a full round crack in a 1-in. irrigation line which ran for 3 years, a full round crack in a 3-in. line in a trailer park which ran for a year, and a leak in a fire service line which ran up $1700 to $1800 monthly bills for several months. The East Bay Municipal Utility District in Oakland, CA,[44] noted that an estimated 8.3 mgd leakage has been detected and repaired through their program. A leak on a 16-in. pump line had been discharging into a storm drain and losing 60 gpm. Another leak of 300 gpm was found in another high-pressure pump line leaking into a gravel creek bed.

Leaks on the consumer side also lose a lot of water. Common sources are toilet tank systems, irrigation systems, and faucet leaks. Kingston[45] estimates water lost in consumer plumbing is four times that lost by the distribution system.

---

[38] J. E. Pilzer; S. E. Sowby, "Leak Detection Programs Recover Revenues," Journal American Water Works Association (November 1981), pp 562-564; W. L. Kingston; G. L. Laverty, "Leak Detection: Modern Methods, Cost, and Benefits," Journal American Water Works Association (February 1979), pp 61-63.

[39] I. E. Pilzer.

[40] S. E. Sowby.

[41] S. E. Sowby.

[42] S. E. Sowby.

[43] G. L. Laverty.

[44] G. L. Laverty.

[45] W. L. Kingston.

5 FORT CARSON WATER USE DISTRIBUTION

Fort Carson has always purchased its potable water from the City of Colorado Springs, CO, because the installation's natural water supply is inadequate. The contract which began 1 October 1978 is based on a maximum demand of 8 million gallons per day, which is 7 percent of the water distributed by the City of Colorado Springs. The average actual use by Fort Carson has increased slightly since 1970 (about 15 percent), although current use is somewhat below that observed in the middle 1970s. Historical water use data are given in Table 8. During FY81, Fort Carson spent $1,325,236 for its water supply: $920,931 for purchasing and producing water (average cost: 76¢/1000 gal) and $404,305 for maintenance of the distribution system.

The water which the installation purchases is considered adequate to meet its current mission. Although Colorado Springs, at its discretion, could legally withhold the water the installation purchases (water is not regulated by the Colorado Public Utilities Commission), it is unlikely to do so.

Fort Carson owns water rights to portions of the flow of the Rock and Little Fountain Creeks. It uses this water for irrigation. The installation has legal rights to ground water at the Turkey Creek Recreation Area, the Rod and Gun Club Area, Camp Red Devil, the Wilderness Ammo Storage Area, Tank Table V, Tank Table VII, Tank Table VIII, and Lytle School (downrange control). The water use distribution analysis given here will include only the water purchased from the City of Colorado Springs supply. The other sources are minor.

Fort Carson was the site of an extensive metering program in 1977, when CERL installed several water meters on representative buildings and activities

Table 8

Fort Carson -- Historical Water Use

Year	Water Used (mgd)
1970	2.71
1971	2.54
1972	3.02
1973	2.80
1974	2.99
1975	3.50
1976	3.68
1977	2.77
1978	3.10
1979	2.76
1980	3.08
1981	3.32

to augment the few meters already present.[46] Data were collected over 3 months. The information gathered in this study was used to derive Fort Carson's water use distribution for the current research.

Based on water production records from October 1978 through August 1982 (47 months), total consumption at Fort Carson follows a clear seasonal cycle. Minimum use occurs during the 5-month period from November through March. Average use during this time was 2.1 mgd, with a sample standard deviation of 0.4 mgd. This level of use may be assumed to represent the installation's basic water requirements, exclusive of such major warm season demands as irrigation. Spring (April and May) and autumn (September and October) have very similar water usages. During April and May, water consumption averages 3.2 mgd, with a sample standard deviation of 0.9 mgd. April use is usually higher than May use, probably because of May's higher average rainfall. Irrigation use is inversely proportional to natural precipitation. September and October, also transitional months, show an average 3.0 mgd usage, with a sample standard deviation of 0.5 mgd. The lesser variability may result because autumn precipitation has less effect on irrigation.

Peak water use at Fort Carson occurs in summer, from June through August. The average for this season is 4.2 mgd, with a sample standard deviation of 0.9 mgd. In July, the hottest and dryest month, water use reaches 4.9 mgd. In July 1980, the monthly average was 5.4 mgd.

Table 9 summarizes these overall water use statistics, and Figure 9 presents them graphically. Thirty percent of the annual water consumption occurs during the five winter months. Thirty-five percent occurs during the four transitional months of spring and autumn. The remaining 35 percent is used in the summer months. The annual average use is approximately 3.0 mgd.

On a yearly basis, family housing uses the most water. There are 1829 units of family housing on the installation. The occupants receive no bill for their water consumption (most of these units are unmetered). However, family housing water use is estimated by extrapolation from a few meters installed for sampling to determine a basis for an internal funds transfer between Directorate of Engineering and Housing (DEH) offices. The average amount of water billed to family housing during Fiscal Years 79, 80, and 81 was 977,000 gpd, or about one-third of the installation's total water use. Figure 10 summarizes 45 months of water use data from October 1978 through June 1982. The yearly pattern is similar to that of installation total water use, except that the high summer demand begins in July rather than June.

The population of the family housing at Fort Carson averages about 7330. There are an average of four persons in each of the 1829 family housing units. Per capita water use during the year varies from a low of 72 gpd in January to a high of 238 gpd in July. Averaged across the entire year, 177 gpcd are used. The January use is comparable to that observed in municipalities. The

---

[46] CERL Interim Report N-34.

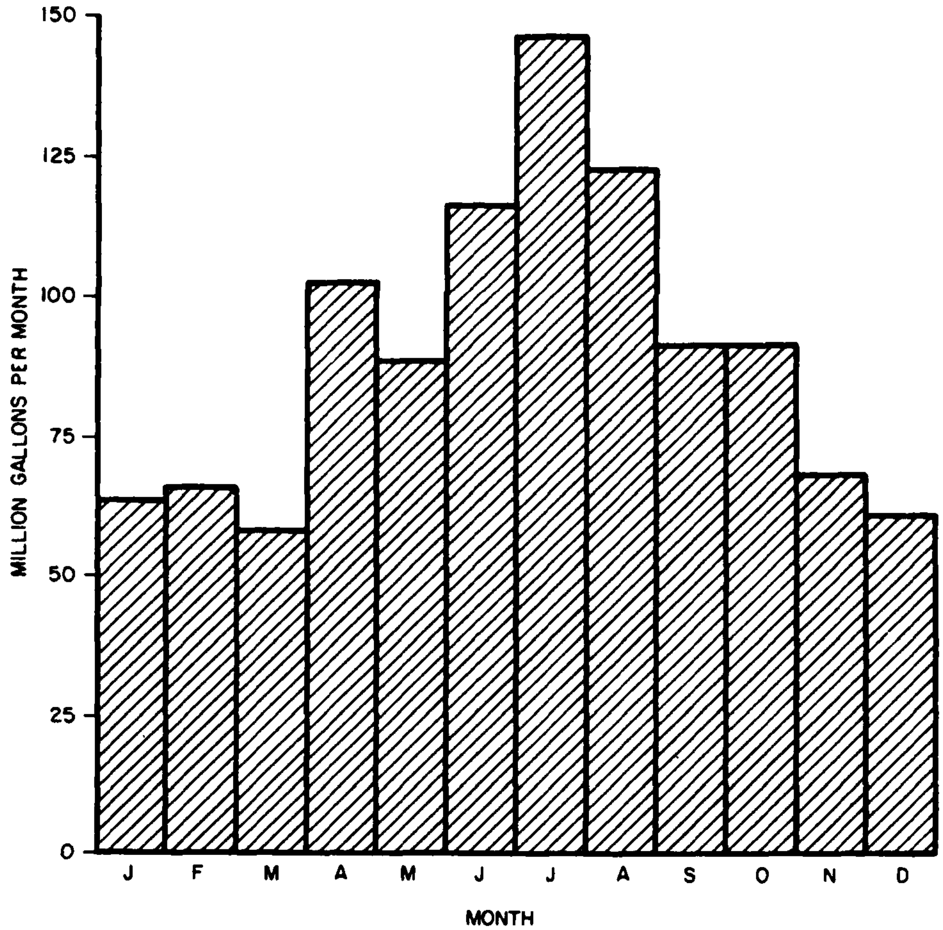


Figure 9. Monthly water use at Fort Carson.

Table 9

Distribution of Fort Carson's Water Use During the Year

Season	Months	Use (mgd)	Standard Deviation (mgd)
Winter	Nov - Mar	2.1	0.4
Spring	Apr - May	3.2	0.9
Summer	Jun - Aug	4.2	0.9
Autumn	Sep - Oct	3.0	0.5

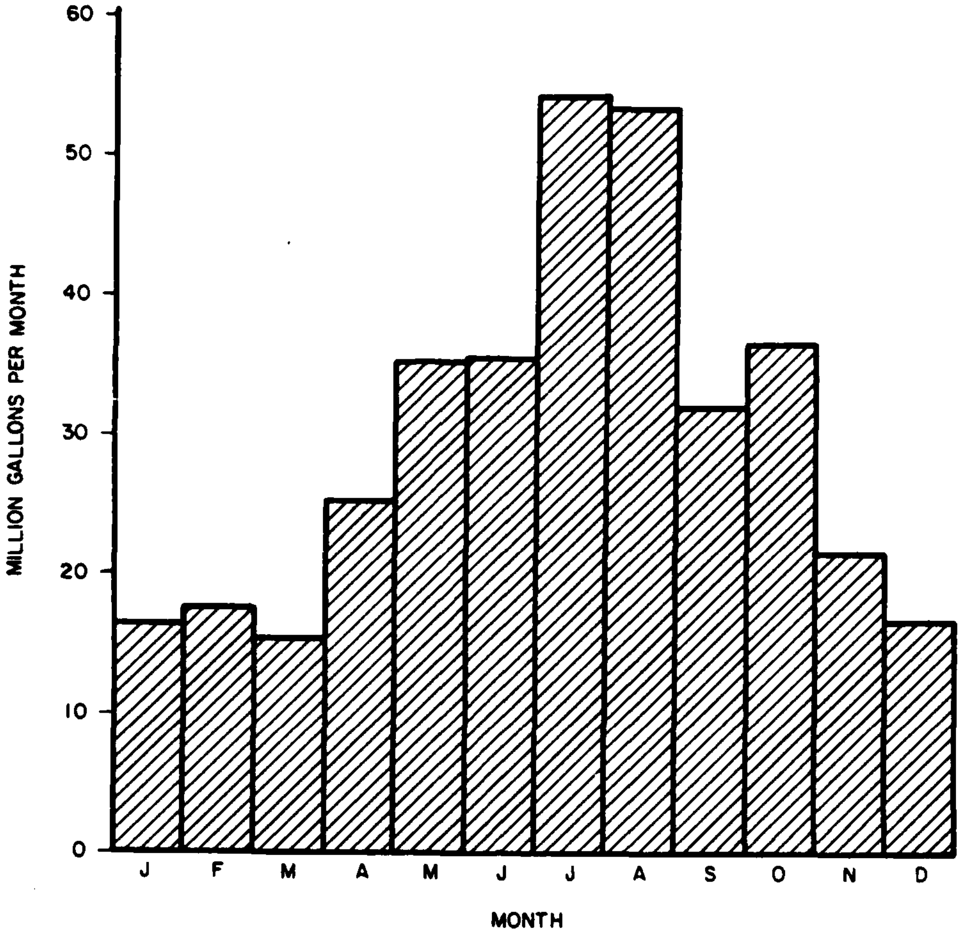


Figure 10. Family housing use at Fort Carson.

summer use is quite high, probably due to intensive lawn irrigation. Significant water savings might be achieved if a few extreme water use rates could be moderated (up to 11,000 gal/household/day).

Figure 11 presents the frequency distribution for water consumption rates (gpcd) of Fort Carson family housing units metered during the first week of January 1977. Per capita water use averaged 98 gpcd that week, with 93 percent of the households using fewer than 150 gpcd. One household used more than 300 gpcd. This extreme rate may be due to a leak, or it may simply reflect the wide variations in water use which occur in family housing. These variations become very apparent during summer peaks; per capita use greater than 2000 gpcd was recorded, while the median use was only 260 gpcd. Figure 12 presents the frequency distribution for water consumption rates in the metered family housing units for the third week of June 1977. A quarter of the metered households used more than 500 gpcd, an exceptionally high use rate which can only be attributed to irrigation. Since the turf requirements cannot have varied this much (or to this extreme), there is a potential for water savings through education of family housing residents.

The basic water requirements of family housing residents were estimated as the average of the November through March cold season usage, which is 78

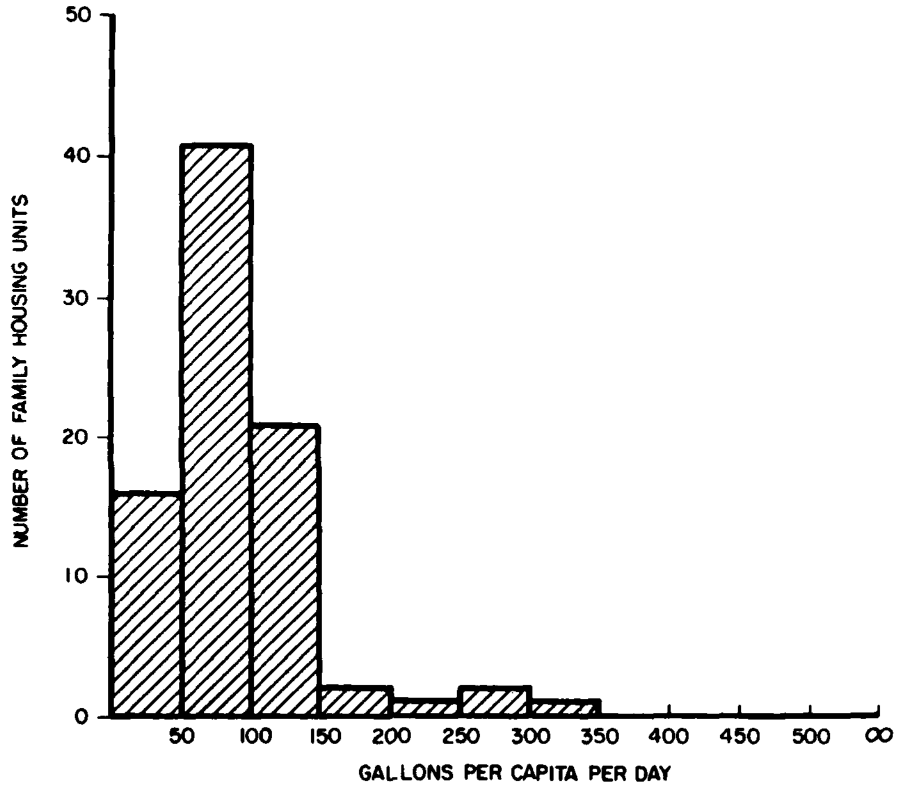


Figure 11. Frequency distribution for Fort Carson family housing water use (first week of January).

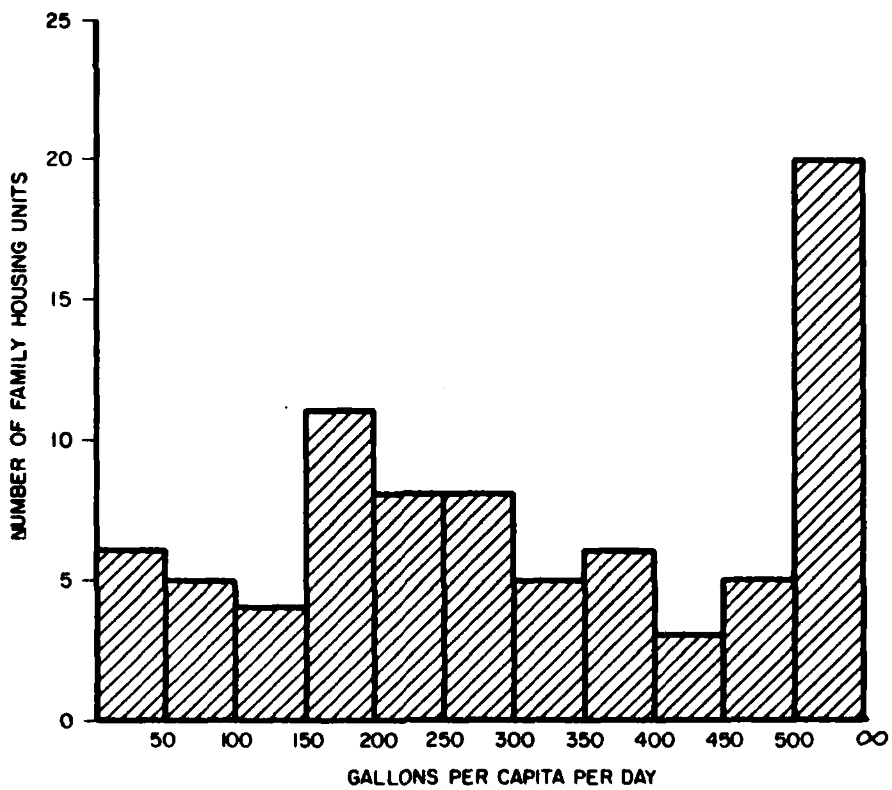


Figure 12. Frequency distribution for Fort Carson family housing water use (third week of June).

gpcd; it was then possible to approximate the proportion of family housing water use which goes to irrigation and other warm season uses (e.g., car washing). This was found to be about 40 percent of the yearly water use. In terms of the total water involved, about 150 million gal are used for irrigation each year.

About 19,000 military personnel are normally assigned to Fort Carson (18,985 was the FY79 average). Some of these people live in family housing (1829, assuming one per family housing unit); others (6350) live off-post. Thus, using the FY79 military population as a basis for estimation, 10,806 military personnel were living in nonfamily housing (barracks, BOQ, etc.). CERL's 1977 metering study determined that average troop housing water use was 52 gpcd. Using this factor for all personnel in nonfamily housing and adding 20 gpcd for meals (the 1977 study showed that messhalls used about 10 gal per meal served; 2 meals per day were assumed to be eaten in mess halls), the water requirements of nonfamily housing military personnel can be estimated at 72 gpcd, or 0.78 mgd for 10,806 people. This would amount to 284 million gal in one year.

Fort Carson bills a variety of users (other than family housing) for their water. These include Bergstrom AFB, the Commissary, NORAD's Cheyenne Mountain Complex, the Officer's Club, package beverage stores, Defense Property Disposal Office (DPDO), the Rocky Mountain Area Exchange, the Fort Carson National Bank, the Credit Union, School District 8, the Corps of Engineers Area Office, and a variety of contractors. Despite the number of these other users, their cumulative use is low. Family housing accounts for 93 to 95 percent of the total billed (reimbursable) use. In FY79, nonfamily housing reimbursable water use totaled about 27 million gal.

Industrial facilities such as motor pools, washracks, and maintenance facilities use large amounts of water. The 1977 metering data collected by CERL showed individual washracks using more than 17,000 gpd and motor pools using 3500 gpd. The consolidated maintenance facility (Building 8000) used 14,000 gpd. Despite the importance of industrialized water use, it will be necessary to estimate it in this study as part of the water unaccounted for by other uses. One reason is that water use data on the many diverse industrial activities is insufficient. Another is that the status of the many industrial facilities in the installation's inventory is uncertain.

To plan its water supply, the Army has traditionally counted civilians and off-post military personnel as equivalent to one-third of an installation resident. About 6350 military personnel live off-post, and 2600 civilians work on-post. (Two thousand civilians work for the installations; 588 work at the PX and non-appropriated fund facilities.) Assuming that these individuals use one-third of the basic 150 gpcd water allotment, they would require 163 million gal per year. However, this is unrealistically high. The 150 gpcd factor includes irrigation, commercial, and industrial requirements which this study accounts for elsewhere. Moreover, civilians working at Fort Carson probably don't use one-third of the normally allotted domestic requirement of about 75 gpcd, since they do not bathe, wash dishes, or do their laundry at work. The 588 PX and nonappropriated fund employees have been counted under reimbursable water use. It is probably reasonable to estimate civilian water use at 15 to 20 gpcd or, at most, 15 million gal per year.

Table 10 presents the yearly water use distribution, based on these figures. Nine percent of the water supply is assumed lost to leakage. Figure 13 depicts this information in the form of a pie chart. Figure 14 presents the January estimated distribution, and Figure 15 gives the July estimated distribution. Note that during the hottest period of the summer (July), 55 percent of the installation's water supply is apparently being used for irrigation.

Appendix A provides additional data about Fort Carson water use.

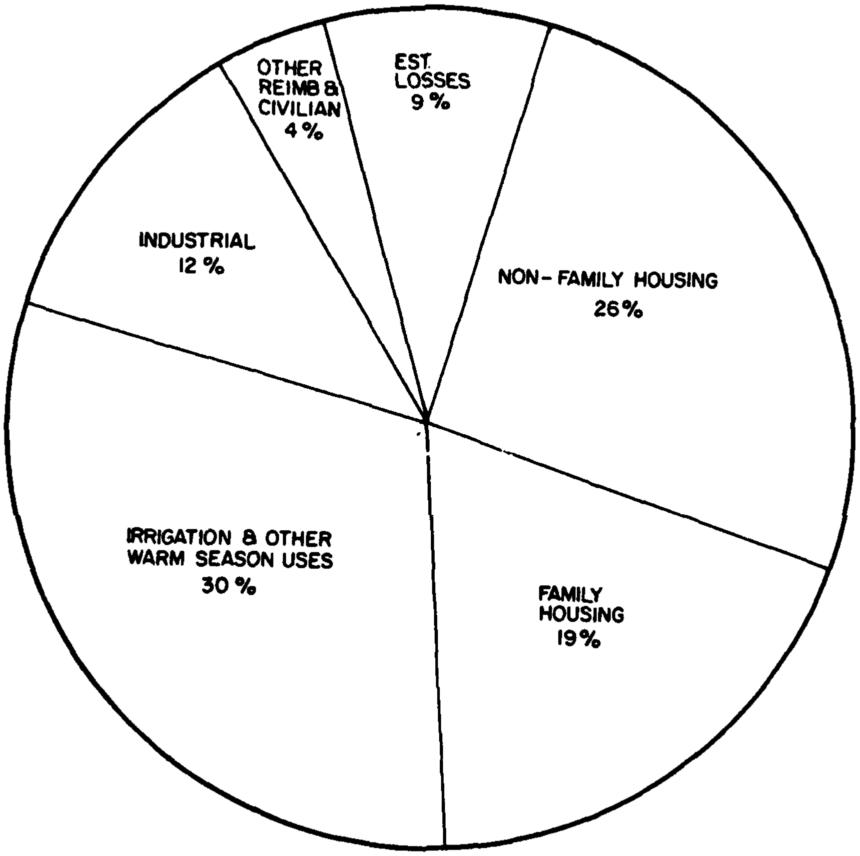


Figure 13. Yearly water use distribution -- Fort Carson (3 mgd average).

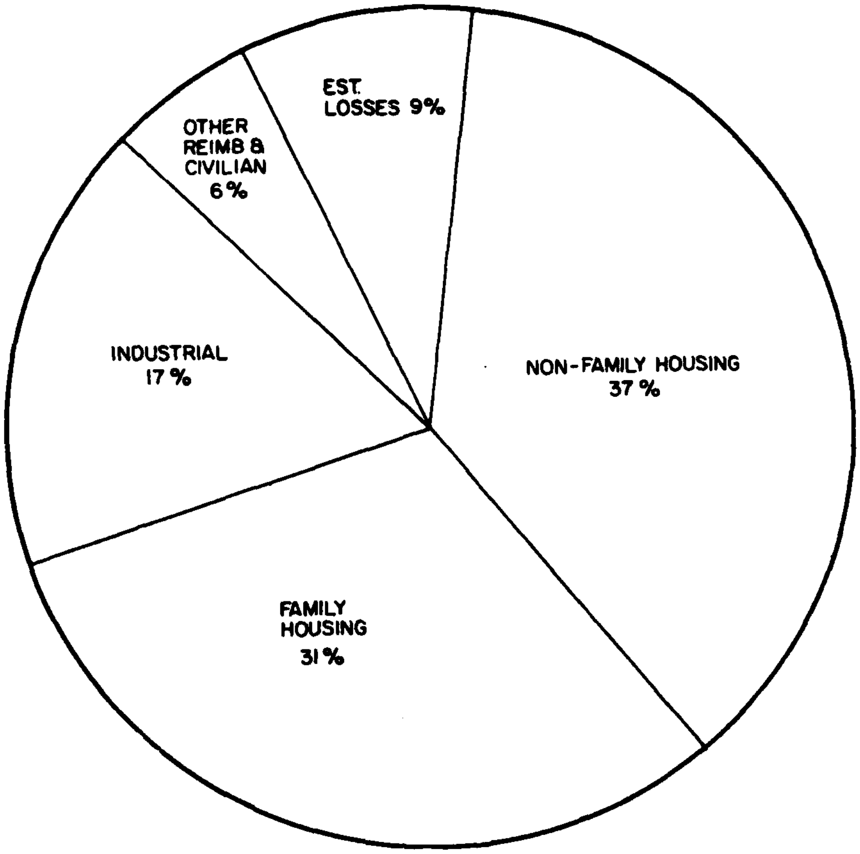


Figure 14. January water distribution - Fort Carson (2.1 mgd average).

Table 10

Yearly Water Use Distribution - Fort Carson

Use	Million Gallons	Percent
Nonfamily Housing (Includes Mess)	323	26
Family Housing (Excludes Irrigation)	209	19
Irrigation	320	30
Family Housing	(150)	(14)
Other	(170)	(16)
Industrial	130	12
Reimbursable Users (Other than Family Housing)	27	2.5
Civilian Employees	15	1.5
Estimated Leakage	93	9
	1078	100

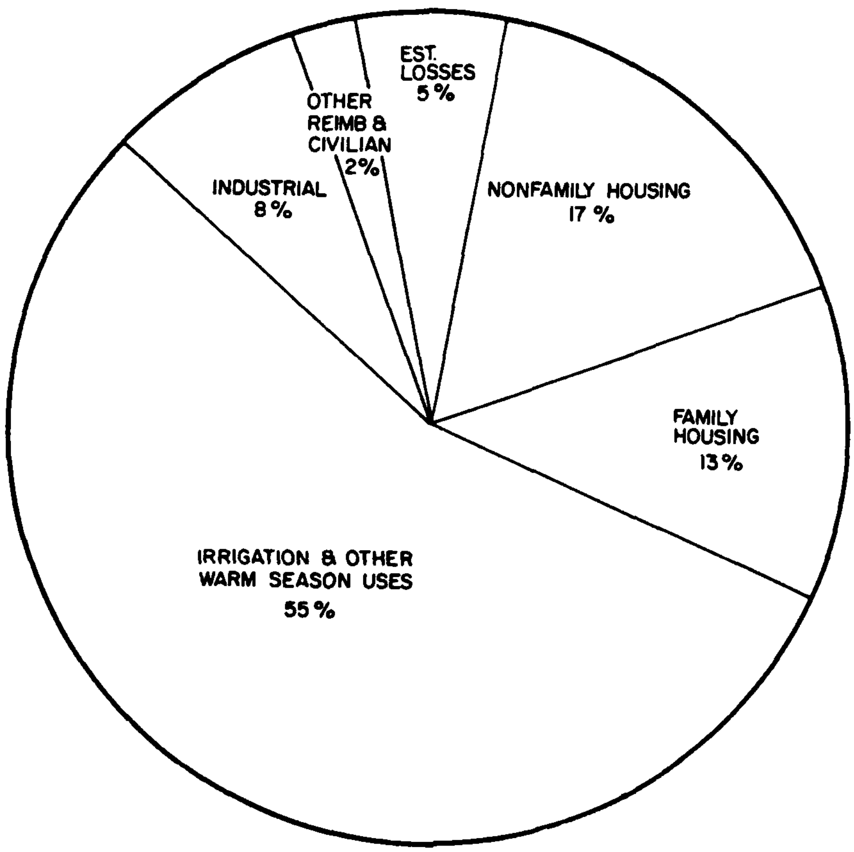


Figure 15. July water use distribution - Fort Carson (4.7 mgd average).

6 FORT LEWIS WATER USE DISTRIBUTION

Fort Lewis superficially appears to have little problem with water shortages. The climate is humid, with ample rainfall, and there are many lakes, streams, and springs. The geological uniqueness of the soil creates a tremendous irrigation demand for maintenance of the lush turf common to the area. The post is situated on glacial outwash composed of gravel and sand. The infiltration rate is very high, with a low water retention rate. Water passes through the soil extremely quickly, so regular irrigation is needed, even though the environment is humid. A typical lawn in the Fort Lewis cantonment has a large proportion of moss commingled with the turf. During most of the year, several wells usually supply a small portion of the base's water, but in summer, they supply greater quantities. Most water comes from Sequalitchew Spring, from which it is feasible to withdraw additional, larger quantities of water. During FY81, Fort Lewis spent $475,214 for its water supply: $275,461 for purchasing and producing water (average cost: 10¢/1000 gal) and $199,753 for maintenance of the distribution system.

Fort Lewis was selected for a characterization study primarily to contrast its water use with that of the heavy irrigation water use at Forts Carson and Bliss and to compare the other expected use patterns. The surprisingly heavy irrigation consumption at Fort Lewis peaks during the warm summer months. Calendar year 1981 was a typical year and is used to represent the post's water use. Water production averages about 5.36 mgd from January through May, and then begins climbing, reaching a peak of 24.2 mgd in August; the peak in 1982 was 23.8 mgd in June. Table 11 presents monthly and quarterly water production figures for 1981, and Figure 16 presents these values graphically. Irrigation is considered to be all use exceeding 5.36 mgd. Sesqualitchew Spring supplies nearly all water during the nonirrigation months, and the numerous wells add to production during summer. Table 11 shows the production of Sesqualitchew Spring and of the combined wells.

Water use at Fort Lewis has been categorized by family housing; nonfamily housing and mess halls; commercial, industrial, office, and educational; Madigan Army Medical Center area; Veterans Administration Hospital; irrigation; coal pilot plant; and unaccounted and other. Areas serviced by Fort Lewis include Camp Murray (Washington National Guard) and the local Veterans Administration Hospital. The sewage treatment plant also treats sewage from McChord Air Force Base, which has its own water supply. Some meter data are available, particularly for family housing. Other data must be estimated or determined by other means.

CERL had installed water meters on many family housing units during 1978-1979. A few other users have also been metered by Fort Lewis. However, there is a lack of data about many activities which are major water consumers. Table 12 presents a statistical analysis of the family housing water use. In the table, "week" is calendar week, "N" is the number of housing units, "$\overline{X}$" is average water consumed per person per day for that week, and "S" is the standard deviation. Values cover parts of 2 years. Figure 17 graphically depicts the tremendous increases during July and August. Family housing use is then estimated basewide by multiplying the total number of family inhabitants by

Table 11

Water Production by Fort Lewis - 1981

(Thousand Gallons)

Time Period	Total Quantity	Sesqualitchew Spring	Wells
Jan	175,128	174,940	188
Feb	162,357	162,250	107
Mar	145,224	145,086	138
Apr	175,536	162,190	13,346
May	159,968	129,190	30,778
Jun	191,284	151,196	40,088
Jul	278,658	158,810	119,848
Aug	526,624	218,814	307,810
Sep	325,933	173,500	152,433
Oct	189,474	151,510	37,964
Nov	162,913	142,705	20,208
Dec	154,645	142,098	12,547
1st Qtr	482,709	482,276	433
2nd Qtr	526,788	442,576	84,212
3rd Qtr	1,131,215	551,124	580,091
4th Qtr	507,032	436,313	70,719
Year 1981	2,647,744	1,912,289	735,455

the average use per inhabitant times 91.25 days per quarter. Values are presented in Table 13. Population figures have been estimated. More precise configurations are probably available from the comptroller's office.

Fort Lewis family housing includes a component for lawn irrigation. An adjustment was made to separate the amount of water used for lawn watering from total family housing use. All water over the 120 gpcd baseline for winter months was considered to be for irrigation. Accordingly, the following values should be subtracted from family housing for the irrigation components and added to the unaccounted total, since these values are already included in irrigation.

Time Period	Volume in Million Gallons
1st Qtr	18
2nd Qtr	17
3rd Qtr	181
4th Qtr	0

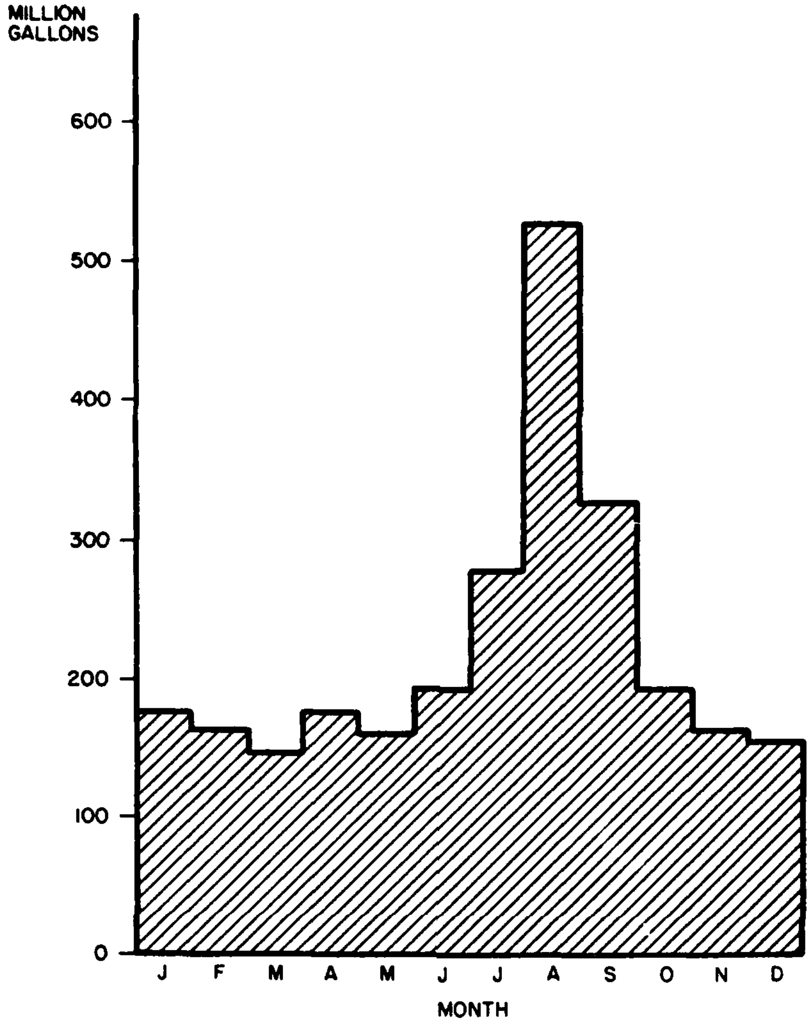


Figure 16. Fort Lewis water production - 1981.

Table 14 shows two classifications of family housing water use: with and without irrigation.

The values for nonfamily housing consumption are estimated. There are an estimated 10,800 troops in the barracks. This value was used to provide a year-round figure. An estimate of 52 gal per person per day was used for water consumption calculations. This value was transferred from a CERL report on water use at Fort Carson. Multiplying these numbers by 91.25 days per quarter gives a water consumption value of 51 million gal per calendar quarter. The obvious assumption made here is that individual troop water use is constant.

A figure for mess halls was obtained by using the same factors used at Forts Carson and Bliss; i.e., multiply number of troops by 10 gal per meal by two meals per day times 91.25 days per quarter. The quarterly use is assumed constant at 20 million gal per quarter. The combined category for nonfamily housing and mess hall totals a constant 71 million gal per calendar quarter.

Table 12

Fort Lewis Family Housing Water Use

Week	N	$\overline{X}$	S	Week	N	$\overline{X}$	S
1	76	98.4	131.5	27	139	216.0	288.3
2	73	93.9	100.4	28	142	314.5	337.5
3	73	91.4	114.6	29	145	421.6	410.2
4	61	90.8	79.2	30	145	440.9	384.7
5	63	103.2	99.2	31	148	617.8	540.7
6	64	84.0	41.2	32	149	403.0	456.0
7	61	89.5	43.9	33	147	346.5	347.8
8	0			34	73	190.8	249.4
9	41	177.4	319.4	35	76	147.6	179.6
10	43	170.5	320.1	36	75	142.4	137.4
11	43	170.7	349.7	37	76	119.2	114.2
12	44	146.4	260.2	38	76	107.4	135.9
13	46	139.0	245.2	39	77	99.9	65.3
14	121	106.6	160.9	40	77	94.6	86.9
15	123	110.3	174.2	41	76	104.9	103.9
16	127	118.5	190.9	42	76	94.2	75.8
17	129	119.3	190.8	43	77	90.0	63.3
18	134	123.9	169.3	44	76	100.5	132.9
19	137	165.3	251.9	45	77	107.2	164.1
20	138	124.3	224.8	46	76	113.8	201.1
21	136	125.9	135.8	47	73	122.8	172.6
22	141	112.9	99.2	48	76	117.4	198.8
23	125	105.3	94.2	49	75	115.2	216.9
24	140	136.8	141.5	50	72	96.7	104.9
25	138	147.3	126.7	51	72	102.7	127.7
26	141	204.7	213.6	52	75	104.1	118.8

N = number of housing units.
$\overline{X}$,S = gal per capita per day.

The Veterans Administration Hospital is an off-post recipient of Fort Lewis water. The data from 1981 listed in Table 15 were taken from meter readings obtained from the utility office.

The Madigan Army Medical Center, which contains 396 beds, is another large water consumer. The utility office has data on the amount of water used in the Madigan area (the area includes 129 family housing units). Subtracting the housing component gives a rough approximation of the Madigan Army Medical Center's water use. Irrigation components are probably represented in the total. (See Table 16 for values.) The large summer increase is probably due primarily to irrigation.

Due to the lack of any metering of irrigation on the base, the volume must be estimated. Large expanses of parade grounds, recreational facilities, golf courses, administrative landscaping, cemeteries, and other turfed areas

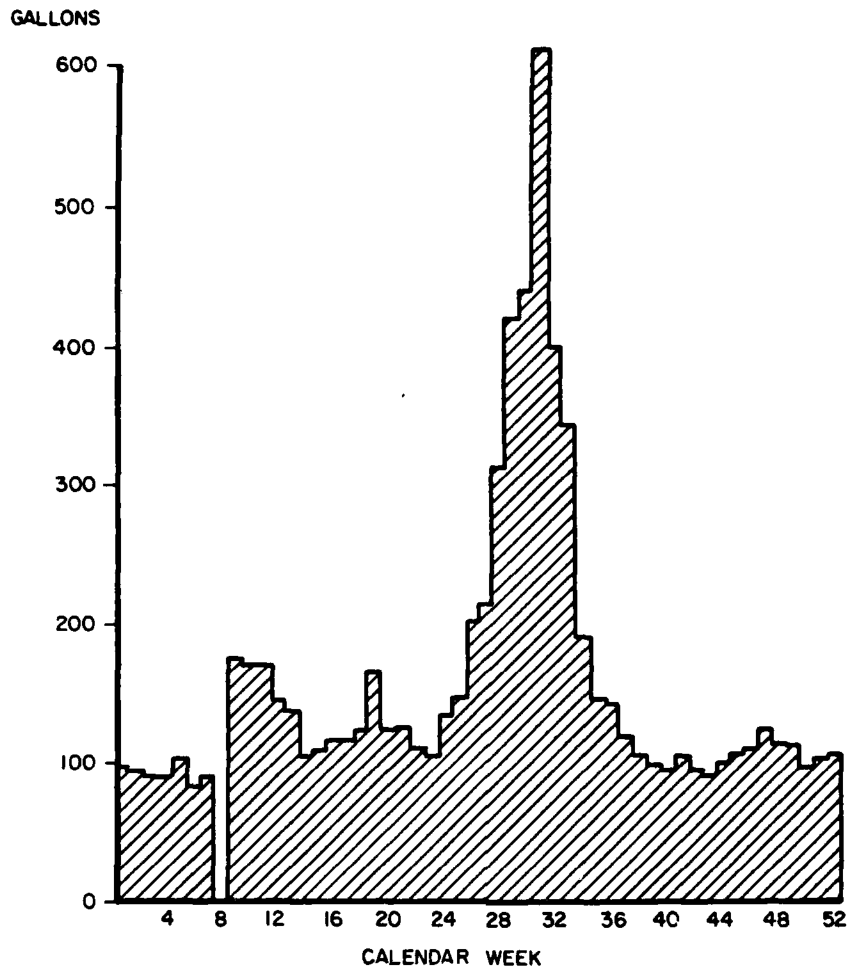


Figure 17. Daily per capita water use in Fort Lewis family housing.

are considered to use all water over the 5.36 mgd winter baseline use. While this quantity is not extremely accurate, a general impression may be obtained. Consideration should also be granted to swimming facilities, increased car washing, and other summer activities. These rough estimates were used to provide the data in Table 17. These values include the component from family housing.

A pilot coal plant which operated during the 1981 calendar year consumed large volumes of water. Although a base engineer estimated that the plant used 2.5 million gal per month, utility records indicate larger volumes. The data given in Table 18 indicate utility record values until November when the plant was closed down. The plant is currently inactive.

Commercial, industrial, educational, and office use was estimated by combining different uses. The post laundry was probably the largest metered consumer, accounting for 2.4 to 8.8 million gal per month. The 8.8 million figure occurred in November; the second highest value was 3.5 million. The average laundry use was 3.5 million gal per month, including the high November value. Additional large individual users were the commissary (0.9 million gal/month), PX car wash (up to 1.4 million gal/month) and the Fort Lewis Lodge (up to 0.7 million gal/month). Total component estimates were made by multiplying the effective base population by 13 gal per user (a representative

Table 13

Family Housing Water Use
(Includes Irrigation)

Time period	No. of Family Housing Residents*	Use Per Resident Gallons)	No. Days	Total (Thousand Gallons)
1st Qtr	12,710	121.3	91.25	140,682
2nd Qtr	12,710	130.9	91.25	151,816
3rd Qtr	12,710	274.4	91.25	318,246
4th Qtr	12,710	10[illegible].9	91.25	121,662
Year	12,710	158	365	732,406

*Estimates

Table 14

Family Housing Water Use
Values (Million Gallons)

Time Period	Total Family Housing	Without Irrigation
1st Qtr	141	123
2nd Qtr	152	135
3rd Qtr	318	137
4th Qtr	122	122
Year	732	517

value from the literature for schools, office, commercial, and industrial users) and adding the laundry use. Data are presented in Table 19. The tactical vehicle shops and vehicle washracks are industrial facilities common at Fort Lewis which use an undetermined amount of water; these are included in the "industrial" category.

Table 20 summarizes the available data and estimates for Fort Lewis. Table 21 presents the percentages. The "unaccounted and other" category includes water losses through aging, corroded pipes. Water losses are detected by melted patches in the snow or by geophones in suspect sections of pipe. Other users are recreational activities, such as social clubs, swimming

Table 15

1981 Water Use by Veterans Administration Hospital

Time Period	Volume in Million Gallons
Jan	2.5
Feb	2.3
Mar	3.5
Apr	8.9
May	3.2
Jun	3.2
Jul	5.5
Aug	9.8
Sep	9.3
Oct	4.1
Nov	3.1
Dec	2.7
1st Qtr	8.3
2nd Qtr	15.3
3rd Qtr	24.6
4th Qtr	9.9
Year	58.1

Table 16

Water Use at Madigan Army Medical Center

Time Period	Total Madigan Use (Thousand Gallons)	Family Housing Use (Thousand Gallons)	Medical Center Complex (Thousand Gallons)
1st Qtr	17,924	5,569	12,355
2nd Qtr	27,788	6,009	21,779
3rd Qtr	98,053	12,597	85,456
4th Qtr	24,978	4,816	20,162
Year	168,743	28,991	139,752

facilities, and bowling alleys, plus facilities like Camp Murray. Heavy industrial users may also be represented.

From the data, it appears that the summer months of July, August, and September impact the most on Fort Lewis' ability to supply adequate water. Irrigation accounts for more than half of that period's water use, but is of minor concern during the rest of the year. Closing of the pilot coal plant will make more water available. The relatively high values for some fiscal year quarters for "unaccounted" may include vehicle washracks and additional irrigation.

Table 17

Irrigation Consumption

Time Period	Amount in Million Gallons
1st Qtr	0
2nd Qtr	33
3rd Qtr	630
4th Qtr	20
Year	683

Table 18

1981 Water Usage Pilot Coal Plant

Time period	Amount in Million Gallons
Jan	23
Feb	18
Mar	15
Apr	14
May	12
Jun	11
Jul	8
Aug	8
Sep	11
Oct	12
Nov	0
Dec	0
1st Qtr	56
2nd Qtr	37
3rd Qtr	27
4th Qtr	12
Year	132

Summarizing the available data into pie charts (see Figures 18 through 22) gives the general use distribution for Fort Lewis. Water production for October through June is relatively stable at about 500 million gal per calendar quarter. The summer months of July, August, and September require more than twice that volume. Family housing and troop housing with mess halls is fairly constant throughout the year if the portion of family housing use devoted to lawn irrigation is neglected. The percentage of total water consumed is halved during the third quarter, and for the year, housing consumption is about one-third of the post's total volume. The other categories vary somewhat throughout the year. Water use at Madigan Army Medical Center peaks during the summer, when it is four times greater than in the other quarters. Total quantities of commercial, office, industrial, and educational consumption remained fairly stable. The pilot coal plant used increasingly smaller amounts through the year until it was closed down, ultimately using 5 percent

Table 19

Fort Lewis Commercial, Office, Industrial, and Educational Use

Volumes in Million Gallons

	Above Quantity	Laundry Use	Total
Qtr 1	31.3	9.0	40.3
Qtr 2	31.3	8.5	39.8
Qtr 3	31.3	9.9	41.2
Qtr 4	31.3	14.7	46.0
Year	125.2	42.1	167.3

Effective base population = 36,935
Gallons per person factor = 13
Number of days per quarter = 91.25 x (5 ÷ 7)
Contribution per quarter = 31.3 million gal

of the yearly volume. The Veterans Administration Hospital followed the same use pattern as the Medical Center, peaking in the summer and consuming the least during January through March. Irrigation was a tremendous water consumer during the warm months, using more than half of the third quarter's available water and one-fourth of the yearly total. The category of "unaccounted and other" is very large for most of the year, but drops during the third quarter. Portions of the "unaccounted" category could probably be assigned to irrigation, while values for water loss percentage are unknown. Industrial use may also be a contributor. Recreational uses are minor.

Appendix B provides additional data about Fort Lewis water use.

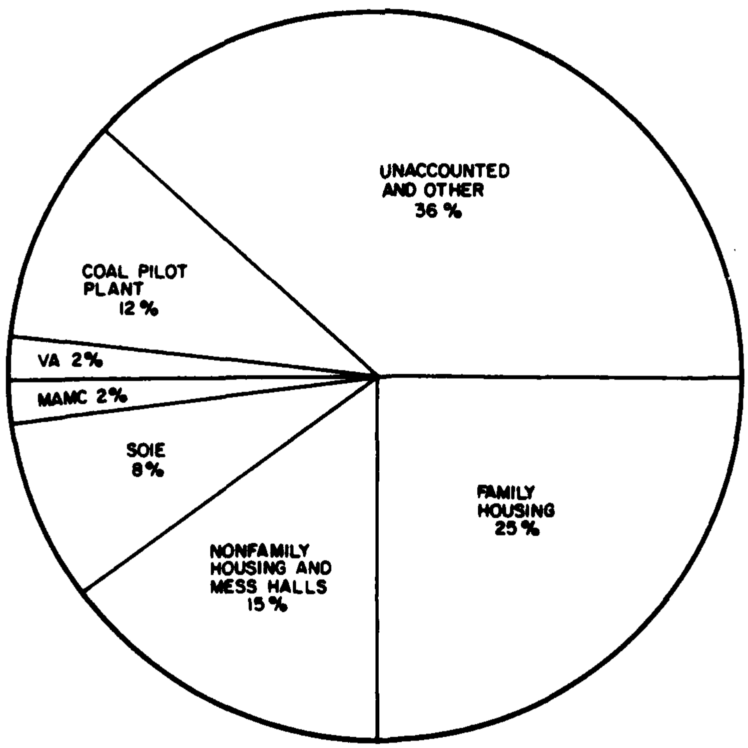


Figure 18. Fort Lewis water use distribution, 1981 -- first quarter.

Table 20

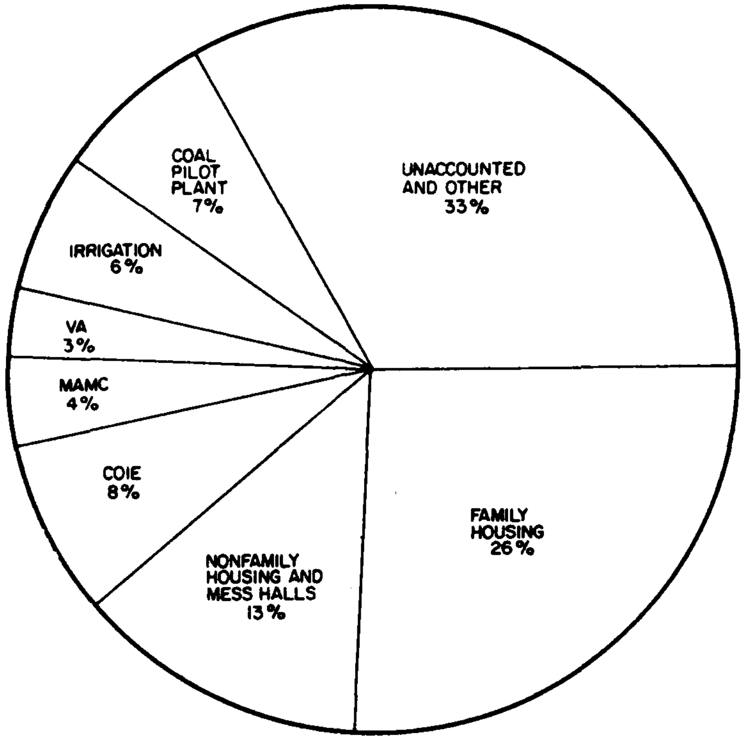
Summary Values of Fort Lewis Water Usage (Million Gallons)

Category	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Year
Family Housing	123	135	137	122	517
Nonfamily Housing and Mess Halls	71	71	71	71	284
Commercial, Industrial, Office, and Educational	40	40	41	46	167
Madigan Army Medical Center	12	22	85	20	139
Veterans Administration	8	15	25	10	58
Irrigation	0	33	630	20	683
Pilot Coal Plant	56	37	27	12	132
Unaccounted and Other	173	174	115	206	668
Total Available Water	483	527	1131	507	2648

Table 21

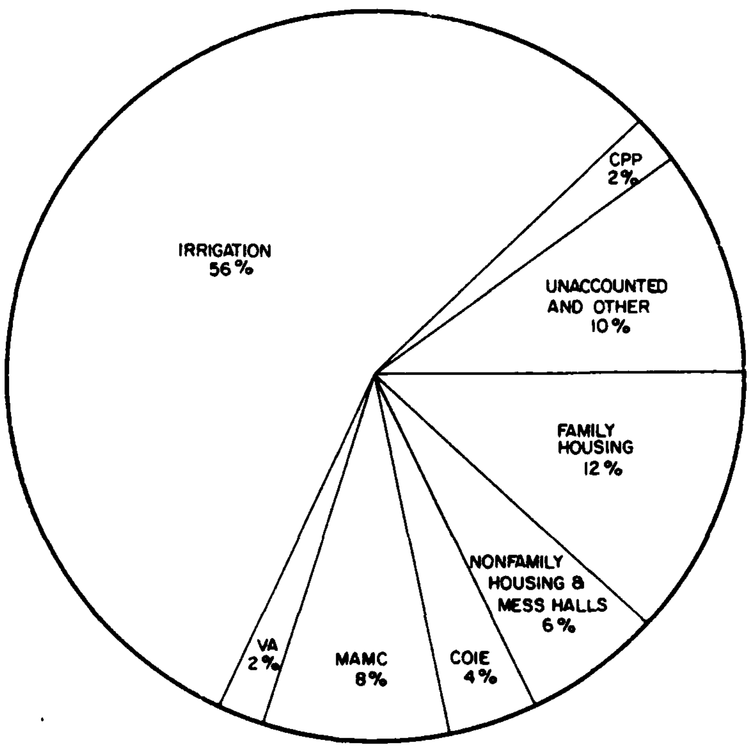
Percentages for Summary Values

Category	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Year
Family Housing	25	26	12	24	20
Nonfamily Housing and Mess Halls	15	13	6	14	11
Commercial, Industrial, Office, and Educational	8	8	4	9	6
Madigan Army Medical Center	2	4	8	4	5
Veterans Administration	2	3	2	2	2
Irrigation	0	6	56	4	25
Pilot Coal Plant	12	7	2	2	5
Unaccounted and Other	36	33	10	41	25
Total Available Water	100	100	100	100	100



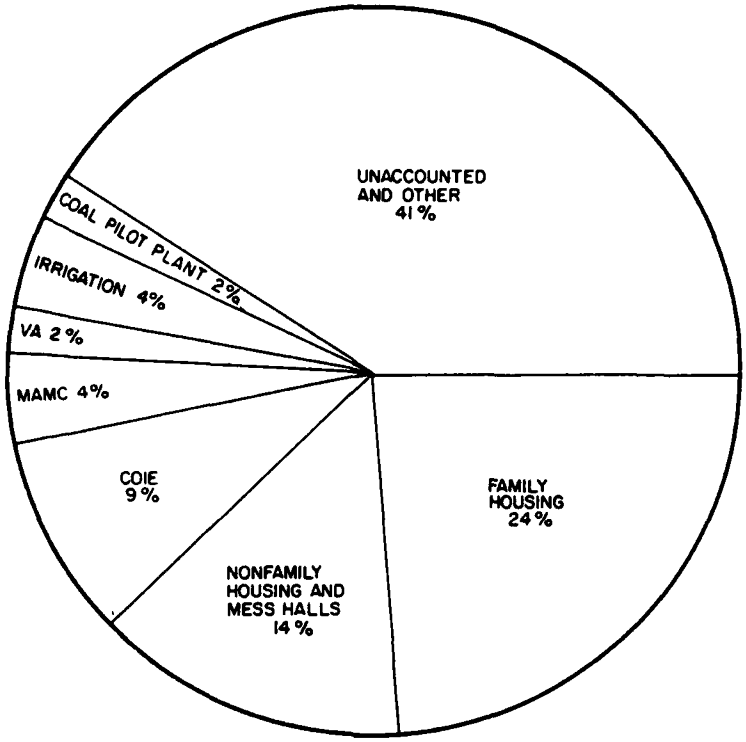
COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
MAMC = MADIGAN ARMY MEDICAL CENTER
VA = VETERANS ADMINISTRATION HOSPITAL

Figure 19. Fort Lewis water use distribution, 1981 - second quarter.



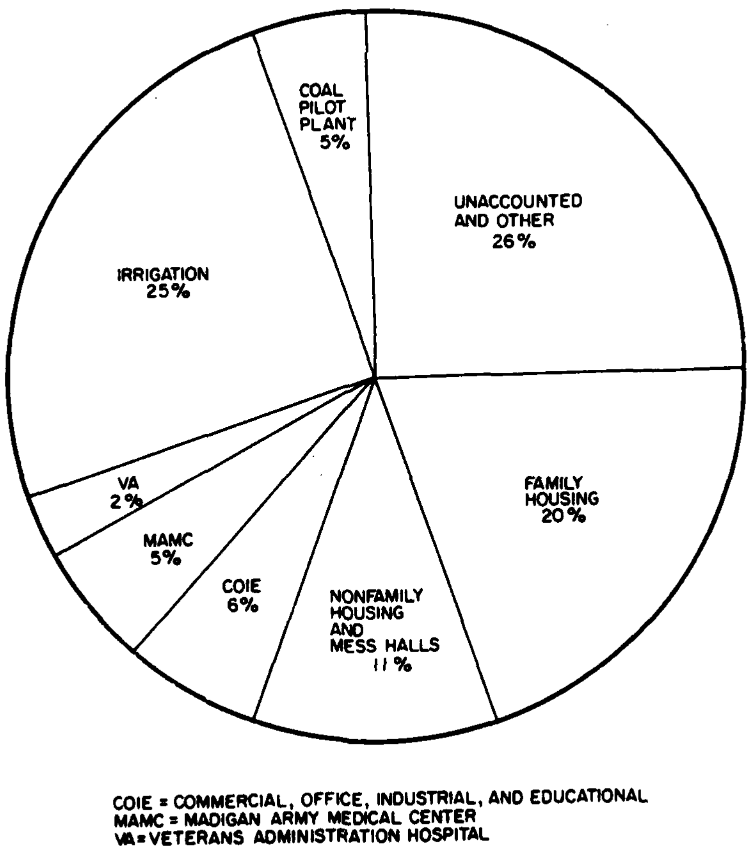
COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
MAMC = MADIGAN ARMY MEDICAL CENTER
VA = VETERANS ADMINISTRATION HOSPITAL
CPP = COAL PILOT PLANT

Figure 20. Fort Lewis water use distribution, 1981 - third quarter.



COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
MAMC = MADIGAN ARMY MEDICAL CENTER
VA = VETERANS ADMINISTRATION HOSPITAL

Figure 21. Fort Lewis water use distribution, 1981 - fourth quarter.



COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
MAMC = MADIGAN ARMY MEDICAL CENTER
VA = VETERANS ADMINISTRATION HOSPITAL

Figure 22. Fort Lewis water use distribution, 1981.

7 FORT BLISS WATER USE DISTRIBUTION

Fort Bliss is an arid area with an annual rainfall of less than 10 in. The rapidly expanding nearby city of El Paso, TX, is currently importing water from New Mexico. El Paso has been mining ground water faster than it can be naturally replaced. The city's well fields and wells border the Fort Bliss boundary. Fort Bliss is also mining water faster than recovery rates and periodically has to lower its pumps and deepen wells to maintain an adequate flow for the base. The situation in the region is approaching critical dimensions, since the ground water supply is not infinite, and the population increase rate shows no sign of reduction. Some conservation methods for new construction are mandatory in the area; these include low-flow flush toilets and an emphasis on desert landscaping. A ground water recharge system is being built on Fort Bliss land by the City of El Paso. This system will be a significant indicator of what can be done to recharge ground water with sewage treatment plant effluent.

During FY81, Fort Bliss spent $896,171 for its water supply: $467,878 for purchasing and producing water (average cost: 21¢/1000 gal) and $428,293 for maintenance of the distribution system.

Fort Bliss is aware that water shortages may occur in the future. There is talk of using low-flow showerheads in the future and of regulating irrigation more strictly. However, there has been no characterization of where Fort Bliss water is used. It is assumed that most water is used for lawn and turf maintenance irrigation and for family housing.

Current irrigation practice for contract irrigation areas is discussed on p 66. Several buildings (8 to 10) have automatic systems. Guidance from the utilities division specifies that irrigation will not be done between 10 AM and 4 PM due to a high evaporation rate and increased power costs for pumping water. This applies to contract irrigation and family housing. Additional guidance specifies that sprinklers should operate only 15 minutes in any locations. Violators receive citations for wasting water.

Water use at Fort Bliss has generally declined during the past several years. However, a large volume of water is still produced, bought, and consumed. About 30 percent of post water is purchased from the City of El Paso, and water meters indicate amounts going to those sections of the post which purchase water from the City. Other meters which monitor individual buildings or areas have also been installed either by the post or by the post with CERL assistance. However, very little water use information is available. Many of the CERL meters have only been read for a few months, and such a small amount of data is insufficient to characterize an area where climate has a tremendous effect on water consumption. Some sketchy data are available from other meters; however, in some cases, maintenance problems or incomplete metering make the values questionable.

Characterizing where and how much water is used on the post required judicious use of assumptions and estimations to complement available historical data. Total water production and consumption at Fort Bliss vary through the year, peaking during the warmer, drier months (see Table 22). Review of the past several years' data indicated that Fiscal Year 1982 would be typical.

Table 22

Fort Bliss - Total Available Water (FY82)

	Amount (Million Gallons)
1st Qtr	364
2nd Qtr	368
3rd Qtr	804
4th Qtr	794*

*Estimate

Values for Fort Bliss are presented in accordance with the fiscal calendar by quarters. Quarters 1 and 2 (October to March) are similar, and lie at the lower end of the water use spectrum. The third and fourth quarters (April to September) comprise the major water use periods, with values that are about 2.2 times greater than those of the other 6 months. Irrigation is the overwhelming difference, although water use for swimming pools (there are nine on the post) and cooling systems contribute significantly. Other major categories include family housing; nonfamily housing and mess halls; and commmercial, industrial, office, and educational.

Water at Fort Bliss comes from two sources. The first is ground water pumped and treated by Fort Bliss and fed into the distribution network. The second source is water which the base purchases in bulk from the El Paso Water Utilities Public Service Board. The Utility Office has records of water purchased by Fort Bliss. The Water Treatment Plant (WTP) Office also maintains records of purchased and pumped water. A small discrepancy in the records is explained by the fact that Fort Bliss supplies water to some minor users far from the main cantonment areas, which were considered negligible for this study. Appendix C provides data on the amounts of water purchased and produced for installation use. Combining the purchased water with the produced water yields the total water available to the post. Results for FY82 are presented using actual data and estimating the water use for missing time during the fourth quarter, FY82.

The total available water is the amount placed in the distribution system for consumptive use for any given time. Figure 23 shows the annual water consumption averaged over the past 5 to 6 years.

Differentiation of overall consumption into water use categories required a variety of techniques and the most appropriate estimating techniques. For purposes of graphic representation (i.e., pie-chart), the following categories were assigned:

1. Commercial, industrial, office, and educational
2. Family housing
3. Nonfamily housing and mess halls
4. William Beaumont Army Medical Center (WBAMC)
5. Irrigation

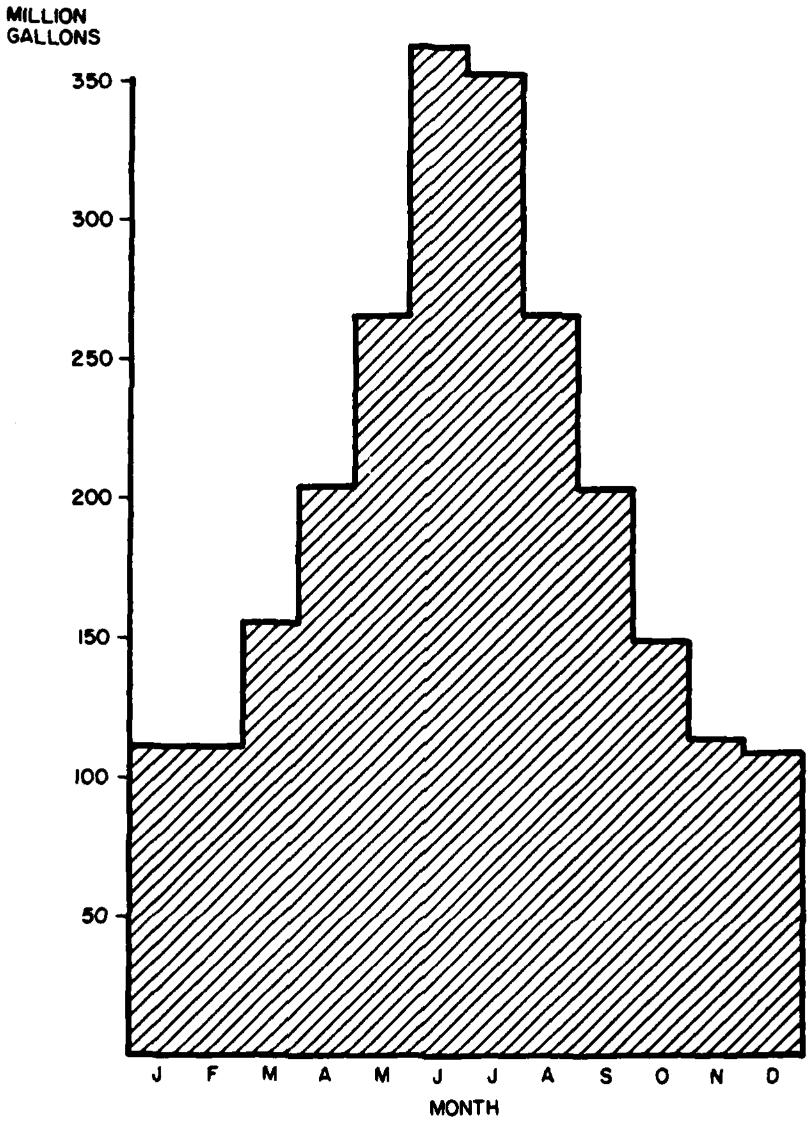


Figure 23. Water consumption at Fort Bliss (average).

6. Swimming pools
7. Other and unaccounted.

Irrigation is one of the major water users on the base. For this study, it is divided into three categories: (1) contract irrigation; (2) "other irrigation" (the golf course and Fort Bliss National Cemetery, both of which obtain their water from Fort Bliss); and (3) family housing. A rough idea of the quantity of water involved can be seen by the 2.2 factor consumption difference between the October-March and the April-September periods. Estimating the amount of water used followed these procedures.

There are 218.5 acres now being irrigated under contract. The contract specifies how often and how long water should be applied in any given area. The quantity of water applied varies with the type of irrigation equipment. Installation personnel did not know how much water was applied, but estimated about 0.25 to 0.50 in. per cycle in areas specified for low-pressure irrigation. One meter had been set up on a section of parade ground, and a few readings for summer months were available. Calculations produced estimates of 1.1 in. of water per cycle on the high-pressure systems, and 0.4 in. per cycle on the low-pressure systems. The high-pressure areas on the parade grounds totaled 51.7 acres. The remaining areas operate under low pressure. Contract specifications indicated the number of cycles per week. Warm-month irrigation specifications called for more water than those of cooler months. Calculation of contract irrigation water consumption assumed full compliance with the contract. The parade grounds are watered daily in April through September and twice weekly during October through March. Two cycles per week are required for the remaining areas during April through September; the contracting officer has the authority to reduce the watering times during the rest of the year. The same authority applies during periods of rain or snow; the contracting officer may relieve the contractor of his/her responsibility. For calculation purposes, one cycle per week for the October to March period for non-parade ground irrigation was assumed. The results in Table 23 indicate a probable worst case and are therefore probably high. Future contracts are being modified to permit the contractor discretion to water only enough to maintain a healthy turf.

Irrigation of the Fort Bliss golf course and the Fort Bliss National Cemetery was put in a separate category called "other irrigation." To estimate golf course consumption, the procedure chosen was to take the known amount of housing units multiplied by the calculated average use per fiscal

Table 23

Fort Bliss Contract Irrigation

	Millions of Gallons
Qtr 1	64
Qtr 2	64
Qtr 3	185
Qtr 4	185

year quarter, plus the calculated barracks use on the existing feeder main to the area. The Logan Heights main is metered since that water is purchased from El Paso. The calculated value was then subtracted from the meter reading and the remainder was assumed to be used by the golf course. Historical values are given in Appendix C for the Logan Heights area. Values for the Fort Bliss National Cemetery were taken from Utility Office records. There is partial metering at the cemetery. While these methods of estimating have the potential for error, the lack of consistent meter data eliminates the obvious best method. (See Tables 24 through 26.)

Assumptions made for irrigation calculations for the golf course used values of 373 family quarters units and 1750 troops in the barracks. Thus, the monthly amount of water to the area - (373 family quarters x amount of water used per quarters per month) - number of troops (1750) x 52 gal per troop per day = golf course use.

The component for irrigation from family housing is then added to the irrigation values to give a total irrigation sum. Family housing irrigation figures are developed in the family housing section (see p 67-70). The combined totals for irrigation are presented in Table 27.

The method of determining water use for family housing uses the following procedure. The Aero Vista housing area has a meter. The Fort Bliss Utilities Division divides the amount of water used per month by the number of fiscal year quarters, resulting in a gallon per quarters per month figure. This number is then multiplied by the total number of unmetered quarters on the

Table 24

Golf Course Water Use (FY82)
(Thousand Gallons)

	Total Logan Hts. Use		No. Qtrs./Use Per Qtrs		Barracks Use		Golf Course
Oct	15578	-	(373)(12.390)	-	2821	=	8136
Nov	14918	-	(373)(10.554)	-	2730	=	8251
Dec	10982	-	(373)(10.178)	-	2821	=	4365
Jan	10310	-	(373)(9.668)	-	2821	=	3883
Feb	14135	-	(373)(9.851)	-	2548	=	7913
Mar	23659	-	(373)(17.522)	-	2821	=	14302
Apr	36001	-	(373)(22.365)	-	2730	=	24929
May	38408	-	(373)(25.846)	-	2821	=	25946
Jun	67902	-	(373)(40.859)	-	2730	=	49932
Jul*	54733	-	(373)(31.747)	-	2821	=	40070
Aug*	36451	-	(373)(21.815)	-	2821	=	25493
Sep*	28886	-	(373)(17.981)	-	2730	=	19449

*Estimates 5-year previous average

Table 25

Water Use at Fort Bliss National Cemetery
(Thousand Gallons)

Oct	446
Nov	389
Dec	158
Jan	153
Feb	577
Mar	735
Apr	4075
May	6198
Jun	6714
Jul	6473
Aug	6228
Sep*	5000

*Estimated values from utility records.

Table 26

Combined Values for Other Irrigation at Fort Bliss (FY82)
(Million Gallons)

Oct	8.3
Nov	8.4
Dec	4.3
Jan	3.8
Feb	8.2
Mar	14.8
Apr	28.7
May	31.9
Jun	56.4
Jul	46.3
Aug	31.5
Sep	24.2
1st Qtr	21
2nd Qtr	27
3rd Qtr	117
4th Qtr	102

Table 27

Total Irrigation at Fort Bliss - FY82
(Million Gallons)

Time Period	Contract Irrigation	Golf Course and National Cemetery	Family Housing Irrigation	Total
Oct	--	8.3	8	--
Nov	--	8.4	2	--
Dec	--	4.3	0	--
Jan	--	3.8	0	--
Feb	--	8.2	0	--
Mar	--	14.8	23	--
Apr	--	28.7	38	--
May	--	31.9	51	--
Jun	--	56.4	100	--
Jul	--	46.3	86	--
Aug	--	31.5	75	--
Sep	--	24.2	42	--
1st Qtr	64	21	10	95
2nd Qtr	64	27	23	114
3rd Qtr	185	117	189	491
4th Qtr	185	102	203	490
Year	498	267	425	1190

procedure is outlined below; monthly and quarterly data are given in Table 28. Historical data are given in Appendix C.

Example: Total gallons of water consumed at Aero Vista housing for Oct 81 = 9,912,000.

Total number of quarters at Aero Vista = about 800.

Average gallons per quarters at Aero Vista for Oct 81 = 12,390 gal.

Total number of military family housing units at Fort Bliss (3582) minus Aero Vista and Van Horn (1600) = 1982 quarters.

Total water consumed for unmetered military family housing = 12,390 gal/qtrs x 1982 qtrs = 24,566 kgal plus metered amounts for Van Horn and Aero Vista = military family housing use.

Family housing water consumption has a large component dedicated to irrigation. An effort was made to separate the irrigation component of family housing category from overall family housing and add it to the irrigation classification. The method used was to take all water over an arbitrary value and classify it as irrigation. Opportunity exists for some minor variances, but the theory is sound. For Fort Bliss, any family housing water use over 35

Table 28

Military Family Housing Water Use (FY82)
(Thousand Gallons)

Time Period	Total	Irrigation Component (est.)	Family Housing Use
Oct	43256	8000	35256
Nov	36637	2000	34637
Dec	34124	0	34124
Jan	33483	0	33483
Feb	33436	0	33436
Mar	58230	23000	35230
Apr	72657	38000	34657
May	85538	51000	34538
Jun	134917	100000	34917
Jul	121129	86000	35129
Aug*	109615	75000	34615
Sep*	77009	42000	35009
		(Million Gallons)	
1st Qtr	114	10	104
2nd Qtr	125	23	102
3rd Qtr	293	189	104
4th Qtr*	308	203	105
Year	840	425	415

*Estimates derived from previous 5-year average.

million gal a month was attributed to irrigation. Table 28 shows the adjustment figures to be subtracted and the final values.

Figure 24 presents family housing water consumption, including irrigation; the figure indicates that water use peaks in the hot months, and shows an approximate bell curve distribution.

Water use in nonfamily military housing was computed with the following guidelines. The Fort Bliss Housing Office gave an estimate of 10,700 people of nonfamily status residing on the post during any month. This was multiplied by a factor of 52 gal per day per occupant, which was obtained from a water use profile of Fort Carson[47] and assumed to be typical of a semi-arid region. This value was held stable through the year at 50.6 million gal per quarter.

[47]CERL Interim Report N-34.

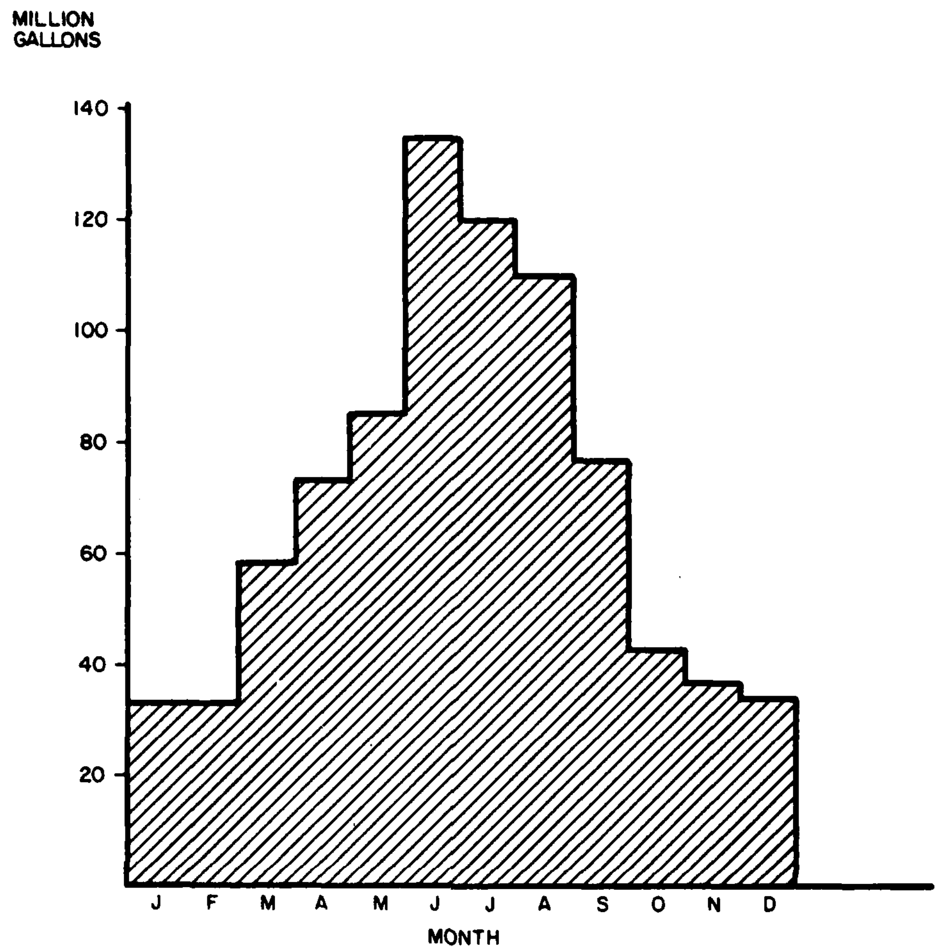


Figure 24. Family housing water use (including irrigation at Fort Bliss, FY82.

Mess halls consume a significant portion of water. Assuming 10,700 non-family housing occupants and feeding them twice a day, with a gallons per meal factor of 10, 19.5 million gal of water are used per fiscal quarter. This value was maintained throughout the year for this study. The gallons per meal factor of 10 is derived from CERL Interim Report N-34 and compares favorably with literature values. Combining nonfamily housing with mess halls gives a quarterly contribution of 70 million gal per quarter.

Water use at the William Beaumont Army Medical Center was estimated. This required knowing the amount of water pumped to a nearby tank which serviced the Upper Beaumont area. The estimated amounts for the family and billet housing were then subtracted from this amount. An adjustment for irrigation was also included. The procedure and results are shown in Table 29. Appendix C gives additional historical data for water in the Upper Beaumont tank.

Commercial, office, industrial, and educational uses were combined into one category. Deriving suitable values involved several components. The commercial component was compiled by obtaining utility billing records for the

Table 29

William Beaumont Army Medical Center Use

Use = Upper Beaumont Water Tank - [144 (number of quarters in area) x monthly average housing use] - [(number of troops in barracks) 200 assumed x 52 gal per person/day] - [5.4 acres of irrigated grounds x 10,000 gal per acre according to contract specifications for irrigation]

FY82 Values in Gallons

	U.B. Tank	Family Use	Troop Use	Irrigation	Use in Million Gallons
Oct	11695000	(144)(12390)	200(52)(31)	5.4(10000)(4.4)	9.4
Nov	11677000	(144)(10554)	200(52)(30)	5.4(10000)(4.3)	9.6
Dec	11677000	(144)(10178)	200(52)(31)	5.4(10000)(4.4)	9.7
Jan	10417000	(144) (9668)	200(52)(31)	5.4(10000)(4.4)	8.5
Feb	9673000	(144) (9851)	200(52)(28)	5.4(10000)(4.0)	7.7
Mar	12693000	(144)(17522)	200(52)(31)	5.4(10000)(4.4)	9.6
Apr	16846000	(144)(22365)	200(52)(30)	5.4(10000)(8.6)	12.9
May	15761000	(144)(25846)	200(52)(31)	5.4(10000)(8.8)	11.2
Jun	25255000	(144)(40859)	200(52)(30)	5.4(10000)(8.6)	18.6
Jul*	20873000	(144)(31747)	200(52)(31)	5.4(10000)(8.8)	15.7
Aug*	16605000	(144)(21815)	200(52)(31)	5.4(10000)(8.8)	12.9
Sep*	14995000	(144)(17981)	200(52)(30)	5.4(10000)(8.6)	11.6

Summing quarterly values:

1 Qtr	29 million gallons
2 Qtr	26 million gallons
3 Qtr	43 million gallons
4 Qtr	40 million gallons

* Used FY81

exchange office and commissary, which covered most of the on-base commercial water use (see Appendix C). An estimated 2.0 million gal per month was added for the central laundry -- a large individual user which should be metered completely. Water use by office, educational, and industrial concerns was estimated by multiplying the effective post population (Appendix C) by the accepted value of 13 gpd, assuming a 5-day workweek. A significant contribution is also made by air washers -- the method of evaporative cooling used in the area. An estimated 100 to 125 gpd per unit (supplied by HVAC personnel) was multiplied by the 193 large units, coupled with May through September use, to give values to be incorporated into the commercial, office, industrial, and educational category. Family housing units also use evaporative cooling, consuming 30 to 35 gal per unit per day; this is included in the family housing category. Industrial activities and vehicle washing are minimal water consumers.

Table 30 presents data for FY82 for commercial and industrial use; additional historical data are provided in Appendix C concerning population and commercial water use. Most of the Commissary and Exchange Office (CXO) and commissary values are post estimates. Historically, water use in boiler plants -- another industrial use -- is large. Appendix C contains data concerning soft water produced at WBAMC and at the central laundry.

During the warm months, swimming pools contribute to water consumption. Water for the nine pools, combined with the high evaporation rate in the region, account for more than 4 million gal each quarter they operate. A utility spokesman said that once the pools were full, 20,000 gal per pool per week were needed to maintain them. Values for pool consumption were derived by combining maintenance flow with initial filling quantities.

The final category -- "unaccounted and other uses" -- includes water lost through the transmission system, and recreational activities such as bowling alleys, theaters, and clubs. The values presented are very questionable. The

Table 30

Fort Bliss Commercial, Office, Industrial
and Educational Use (FY82)
(Thousand Gallons)

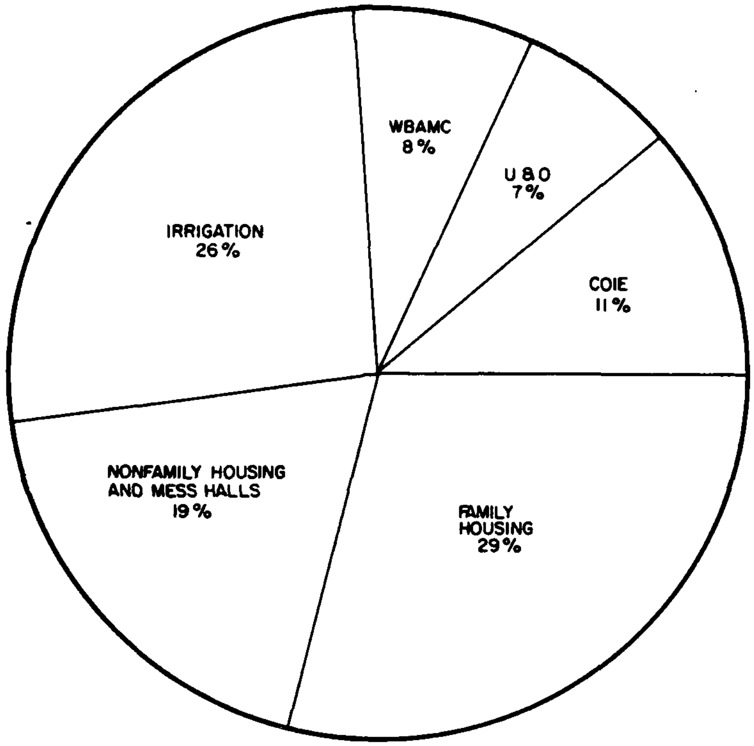
	CXO	Commissary	Air Washers	Office, Educ. & Ind.	Laundry	Total
Oct	2807	561	-	*8200	2000	13600
Nov	2656	534	-	*7900	2000	13100
Dec	2473	351	-	7900	2000	12700
Jan	2464	304	-	8200	2000	13000
Feb	2464	244	-	7500	2000	12200
Mar	2444	308	-	8400	2000	13200
Apr	2623	466	-	10200	2000	15300
May	2673	419	673	8800	2000	14600
Jun	2431	434	651	8400	2000	13900
Jul	2694	536	673	8500	2000	14400
Aug	2735	699	673	*8200	2000	14300
Sep*	2700	650	651	7900	2000	13900
1st Qtr						39400
2nd Qtr						38400
3rd Qtr						43800
4th Qtr						42600

* Estimates

City of El Paso, which has a much newer water supply system than Fort Bliss, loses about 11 percent of its water. Fort Bliss has no leak checking program, so the percentage of water loss is not known. A generous estimate would be at least 15 percent, which would place the sum of pie chart components over 100 percent. This discrepancy may be explained in the following manner. Family housing use may be less than what the base estimates. When irrigation consumption was estimated, no deviation from the contract specifications was assumed. Such deviations may have occurred if irrigation was stopped during periods of rain. The nature of the irrigation equipment also contributed to an imprecise estimate. The method for calculating water use by air coolers assumed constant operation. Calculation of golf course and hospital consumption assumed total use of all water received at those points. Finally, estimates of barracks and mess hall use should be confirmed for the region. It is nearly impossible to identify how many soldiers who are credited with living on the base actually stay there. However, given these and other limitations, the resulting charts are the best available estimate of water use distribution at Fort Bliss.

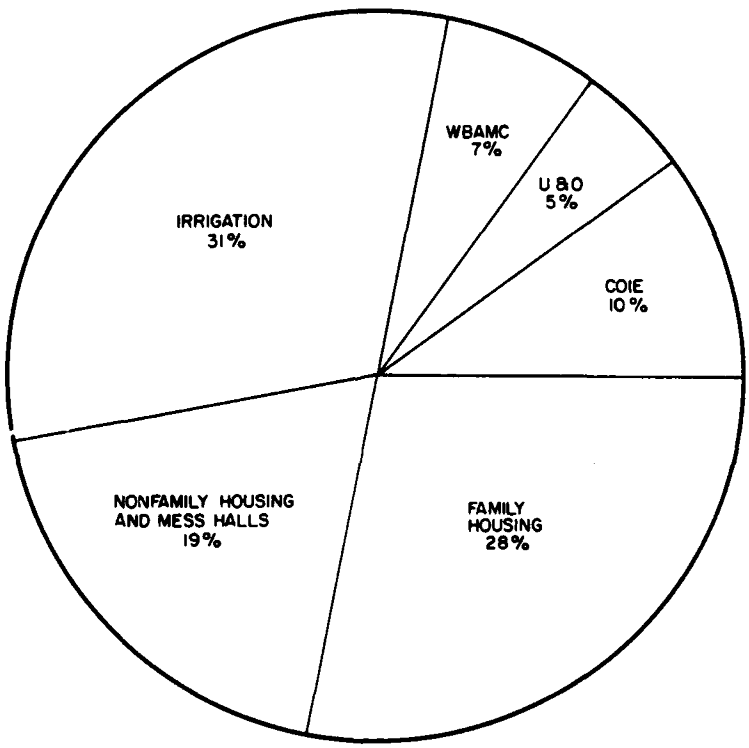
Table 31 shows the various water use values for the different categories. Graphic illustrations are given in Figures 25 through 29. Table 32 gives the percentages dedicated to the different uses. Figures 25 through 29, water use by family housing and nonfamily housing and mess halls, remains fairly constant through the year in terms of total quantities. However, from April to September, the percentage of their total volume is cut by more than half. The commercial, office, industrial, and educational category is also halved during the warmer months. The William Beaumont Army Medical Center and the "unaccounted and other" category show fairly constant percentages through the year.

Irrigation is the base's largest water consumer, using more than 60 percent of the warm-weather water and more than one-fourth of the cool-month water supply. Again, it must be emphasized that the process for estimating water use may be high for irrigation. The "unaccounted and other" category is probably too low by a factor of 3. The year-total pie chart indicates that irrigation accounts for more than 50 percent of total water use. Housing in its various forms uses 30 percent, with the remaining categories splitting the other 20 percent. Any vehicle-washing increase or other increased summer industrial use is probably included in the irrigation portion of the chart.



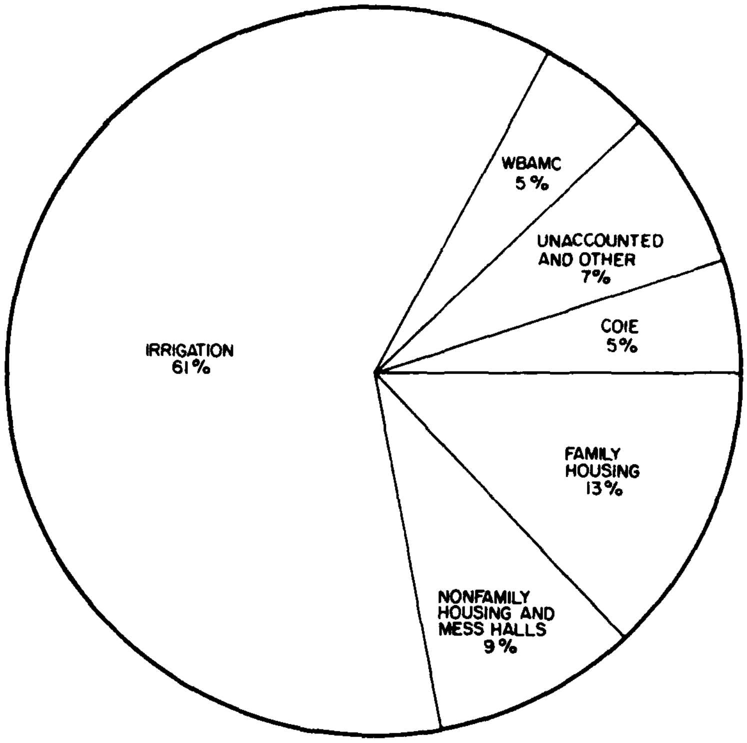
COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
WBAMC = WILLIAM BEAUMONT ARMY MEDICAL CENTER
U & O = UNACCOUNTED AND OTHER

Figure 25. Fort Bliss water use distribution, FY82 -- first quarter.



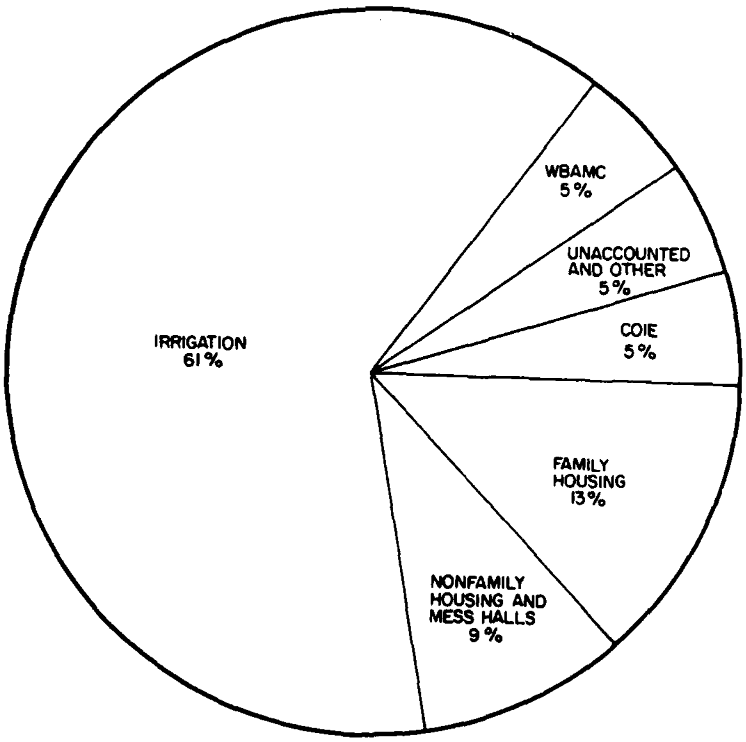
COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
WBAMC = WILLIAM BEAUMONT ARMY MEDICAL CENTER
U & O = UNACCOUNTED AND OTHER

Figure 26. Fort Bliss water use distribution, FY82 -- second quarter.



COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
WBAMC = WILLIAM BEAUMONT ARMY MEDICAL CENTER

Figure 27. Fort Bliss water use distribution, FY82 -- third quarter.



COIE = COMMERCIAL, OFFICE, INDUSTRIAL, AND EDUCATIONAL
WBAMC = WILLIAM BEAUMONT ARMY MEDICAL CENTER

Figure 28. Fort Bliss water use distribution, FY82 -- fourth quarter.

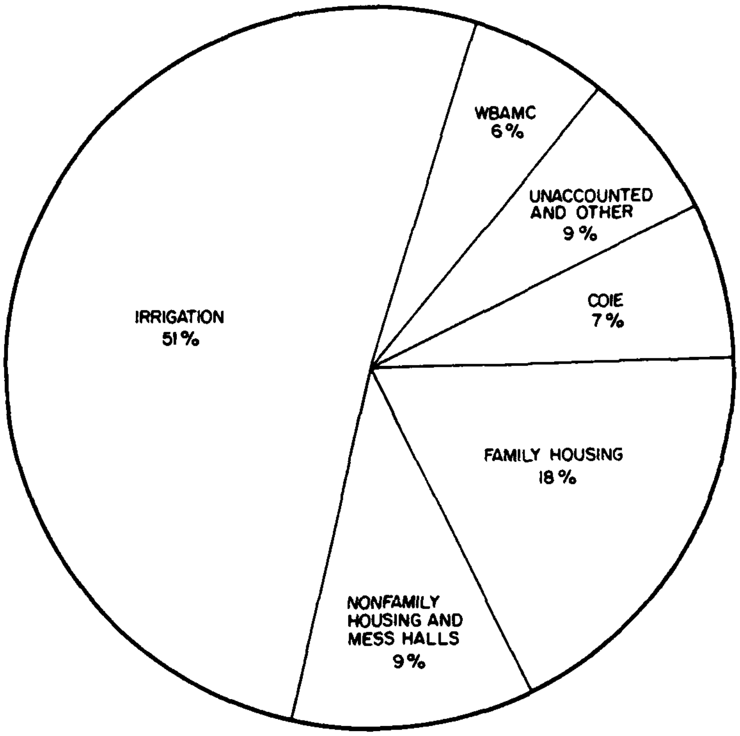


Figure 29. Fort Bliss water use distribution, FY82.

Table 31

Fort Bliss Water Use (FY82)
(Million Gallons)

Category	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Year
Commercial, Office, Industrial, Education	39	38	44	43	164
Family Housing	104	102	104	105	415
Non-Family Housing and Mess Halls	70	70	70	70	280
Irrigation	95	114	491	490	1190
WBAMC	29	26	43	40	138
Swim Pools	-	-	4.4	5.3	10
Unaccounted and Other	27	18	47	41	133
Total Available Water	364	368	803	794	2329

Table 32

Pie Chart Percentages - Fort Bliss

Category	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Year
Commercial, Office, Industrial, Education	11	10	5	5	7
Family Housing	29	28	13	13	18
Non-Family Housing and Mess Halls	19	19	9	12	9
Irrigation	26	31	61	62	51
WBAMC	8	7	5	5	6
Swim Pools	0	0	<1	<1	0
Unaccounted and Other	7	5	6	5	6
Total Available Water	100	100	100	100	100

8 FORT BRAGG WATER USE DISTRIBUTION

Fort Bragg, which is one of the Army's largest fixed facilities, has a very large post population and functions as a mid-sized city. It is located in North Carolina, which has long, hot, humid summers and mild winters. The post's water supply source is adequate. The Fort Bragg water treatment plant draws from the Little River, which has a minimum flow of 20 million gpd. Fourteen deep water wells supply the facilities in the installation's outlying range areas. The post treatment plant feeds Fort Bragg, Pope AFB, and two Army air bases.

During FY81, Fort Bragg spent \$840,927 for its water supply: \$347,727 for purchasing and producing water (average cost: 15¢/1000 gal) and \$493,200 for maintenance of the distribution system.

The water treatment plant can treat 10 mgd; average FY81 production was 6.327 mgd. The range of monthly averages is 5.68 to 7.92 mgd. Total water production for the year was 2309.187 million gal. The figures were similar for FY82; a total of 2493.044 million gal were produced, with an average flow of 6.830 mgd. The monthly averages ranged from 5.61 to 7.58 mgd. Table 33 provides water production records for FY81 and 82. Figures 30 and 31 show the yearly pattern of total water production on post.

Determining distribution of water use at Fort Bragg is difficult because there are no meters and no other information about basic consumption. To achieve its mission, the post supports a heavy daily population, as well as many motor pools, maintenance facilities, and other training mission requirements. The post has 10 swimming pools, 2 golf courses, 19 ballfields, and many other recreation facilities. The Womack Army Medical Center is a large hospital and has many troop medical and dental clinics. For crude estimation purposes, Fort Bragg water use distribution is categorized in the following manner: family housing; nonfamily housing and mess halls; commercial, office, industrial, and educational; warm weather uses; and unaccounted and other.

Family housing consumption at Fort Bragg is an unknown quantity. An estimate of number of family quarters is 4842 units. The following procedure was used to determine overall water consumption for family housing. A 1971 engineering study[48] had run pitometer readings on a section of post containing primarily family housing, plus a shopping center and some offices. Dividing the daily flow measured in this study by the number of fiscal year quarters, after subtracting arbitrary values for the other activities, gave an amount per quarter. This was multiplied by the number of quarters basewide to get a baseline water consumption. The early February value of 380,000 gal minus 10,000 gal for other uses, divided by 1795 quarters, gave 206 gal as a daily average; this was then multiplied by 4842 (units on the post). Multiplication by the number of days per calendar quarter then produced a minimum value for family housing use. Family housing use was assumed constant at 91 million gal per quarter.

---

[48] Report on Engineering Study Water Distribution System U.S. Army Post Fort Bragg, NC, 1971 (Pitometer Associates Engineers, 1971).

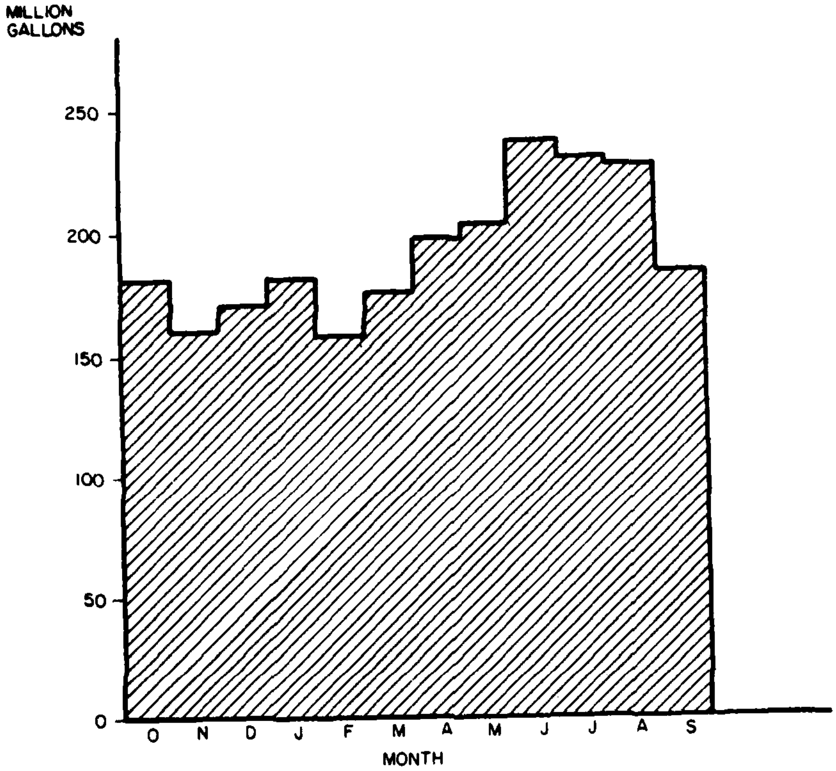


Figure 30. Water production at Fort Bragg, FY81.

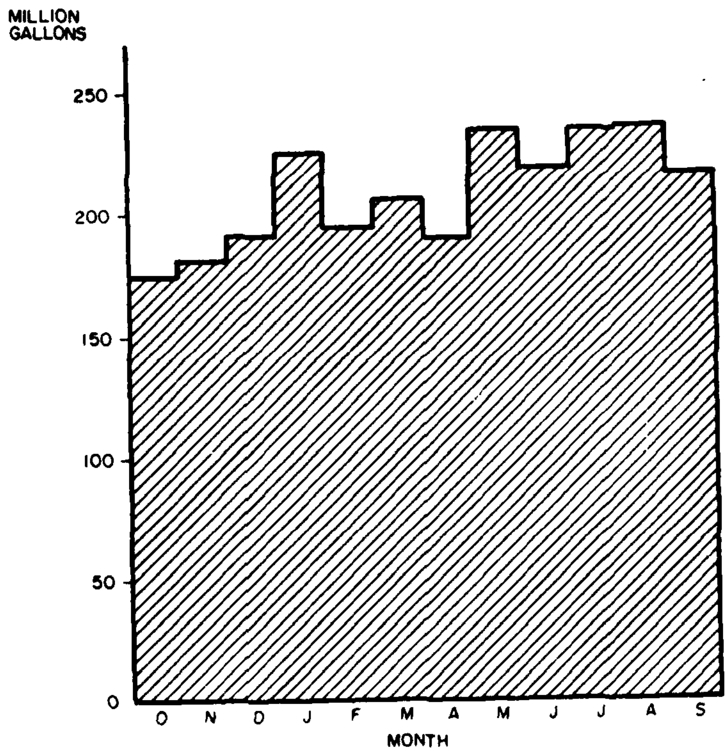


Figure 31. Water production at Fort Bragg, FY82.

Table 33

Fort Bragg Water Production

Time Period	Volume in Million Gallons
FY81	2309.187
Oct	181.785
Nov	160.535
Dec	171.123
Jan	182.672
Feb	158.902
Mar	176.076
Apr	197.497
May	202.194
Jun	237.456
Jul	230.137
Aug	227.854
Sep	182.956
1st Qtr	513.443
2nd Qtr	517.650
3rd Qtr	637.146
4th Qtr	640.947
FY82	2493.044
Oct	173.906
Nov	180.125
Dec	190.136
Jan	226.808
Feb	193.286
Mar	205.197
Apr	189.249
May	233.587
Jun	217.975
Jul	233.819
Aug	234.838
Sep	214.118
1st Qtr	544.167
2nd Qtr	625.291
3rd Qtr	640.811
4th Qtr	682.775

Nonfamily housing and mess hall consumption were the major water consumers post-wide. The large number of barracks spaces, both permanent and temporary, were assumed to be full with 27,600 troops. The values for water consumption at Fort Carson were used to give a constant quarterly water consumption of 181 million gal.

Commercial, office, industrial, and educational consumption was determined by estimation. The reservation's daily population of 68,692 was multiplied by the usage factor of 13 gal per person per day; this figure was multiplied by 91.25 days per quarter. That number was corrected by a 5/7 multiplication factor to obtain workweek amounts. This amount was added to an estimated 3 million gal per month water use by the laundry. While commissaries, shopping centers, and other individual users may have had significant demands, they cannot be included as specific values. The resulting value of 67 million gal per quarter is a rough estimate, since industrial consumption is probably higher due to the large number of tactical vehicle and maintenance shops and washrack facilities for vehicles and airplanes.

Warm weather uses include irrigation, maintenance of the nine outdoor swimming pools, and additional vehicle washing resulting from summer training activities, such as Army reserves. Since no meter data were available, this category was calculated by subtracting the average cool month use from the warm month consumption. The results were:

Warm Weather Use in Million Gallons

Qtr 1	0
Qtr 2	0
Qtr 3	88
Qtr 4	111

The final category -- "unaccounted and other" -- includes several components: the Womack Army Medical Center and other health facilities, additional industrial uses, and water loss through leaks.

Table 34 presents the final estimated Fort Bragg water use characterization. The demand does not fluctuate as wildly as at the western posts because of the much lower irrigation demands. Consumption values are held fairly stable throughout the year due to the method of estimating and assumptions made. Table 35 indicates the percentages involved, and Figures 32 through 36 present the data graphically. On an annual basis, it can be seen that housing demands 45 percent of the total water production. The other categories consume relatively low amounts; for example, water used for warm weather functions is fairly low -- 17 percent at peak quarter use, and 8 percent of the yearly use. The "unaccounted" category may include several subcategories, such as the Womack Medical Center, additional industrial use for vehicle washing, motor pools or other major consumers, recreational use, and water loss from leakage.

Table 34

Fort Bragg Average Water Use Distribution
by Fiscal Quarters
(Million Gallons)

Category	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Year
Family Housing	91	91	91	91	364
Nonfamily Housing and Mess Halls	181	181	181	181	724
Commercial, Office, Industrial, Educational	67	67	67	67	268
Warm Weather Use	0	0	88	111	199
Unaccounted and Other	190	233	212	212	847
Total	529	572	639	662	2402

Table 35

Fort Bragg Average Water Use Distribution
Percentage by Fiscal Quarter

Category	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Year
Family Housing	17	16	14	14	15
Nonfamily Housing and Mess Halls	34	32	28	27	30
Commercial, Office, Industrial, Educational	13	12	10	10	11
Warm Weather Use	0	0	14	17	8
Unaccounted and Other	36	41	33	32	35

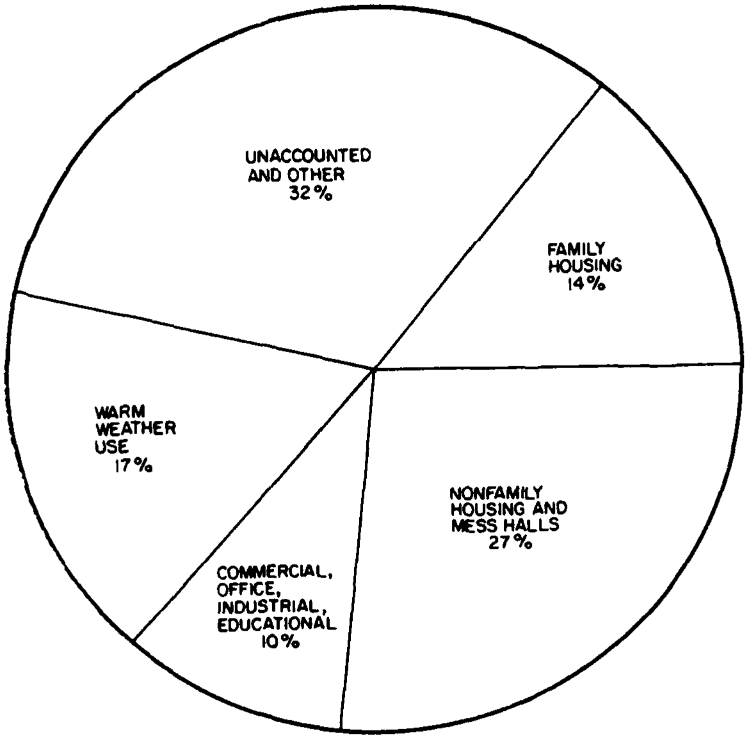


Figure 32. July-September water use distribution at Fort Bragg.

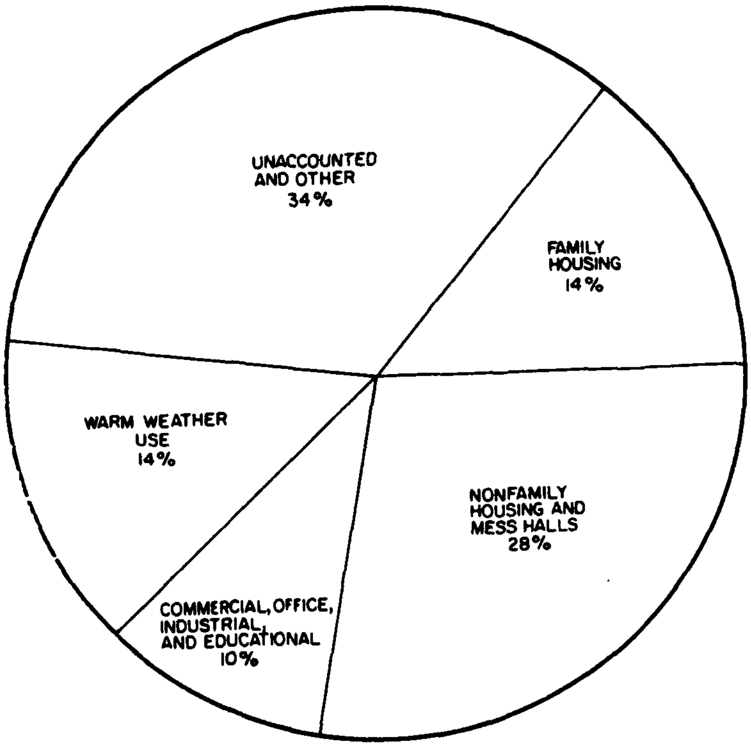


Figure 33. April-June water use distribution at Fort Bragg.

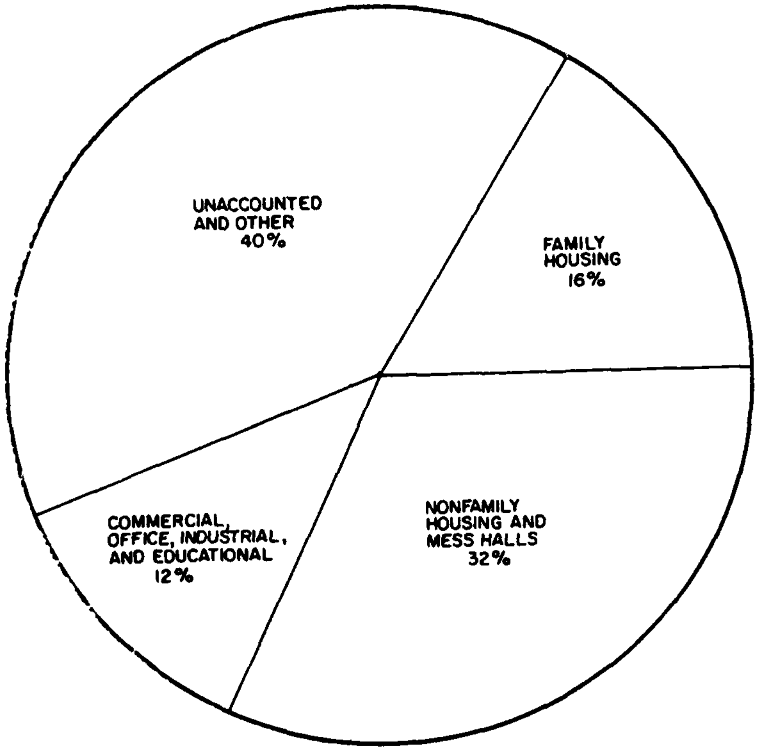


Figure 34. January-March water use distribution at Fort Bragg.

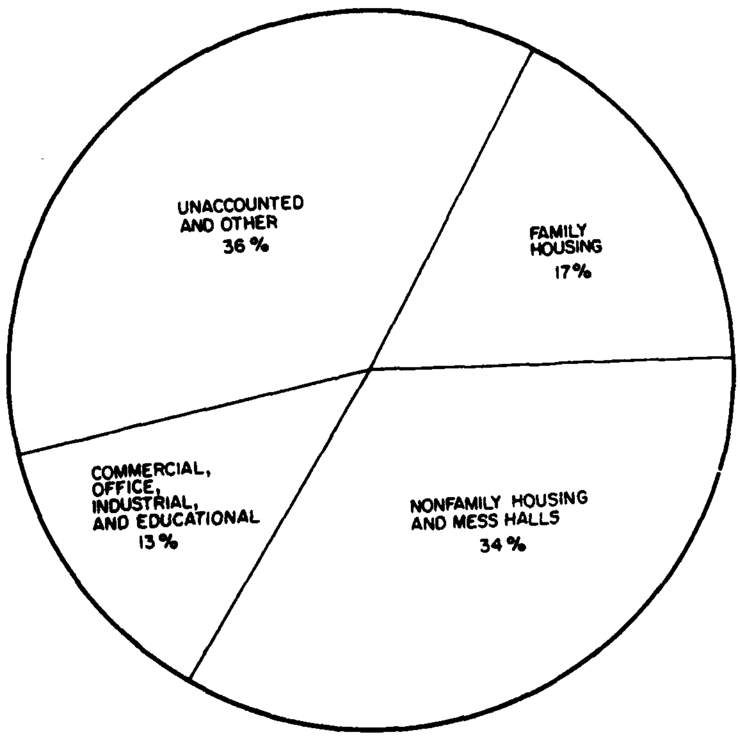


Figure 35. October-December water use distribution at Fort Bragg.

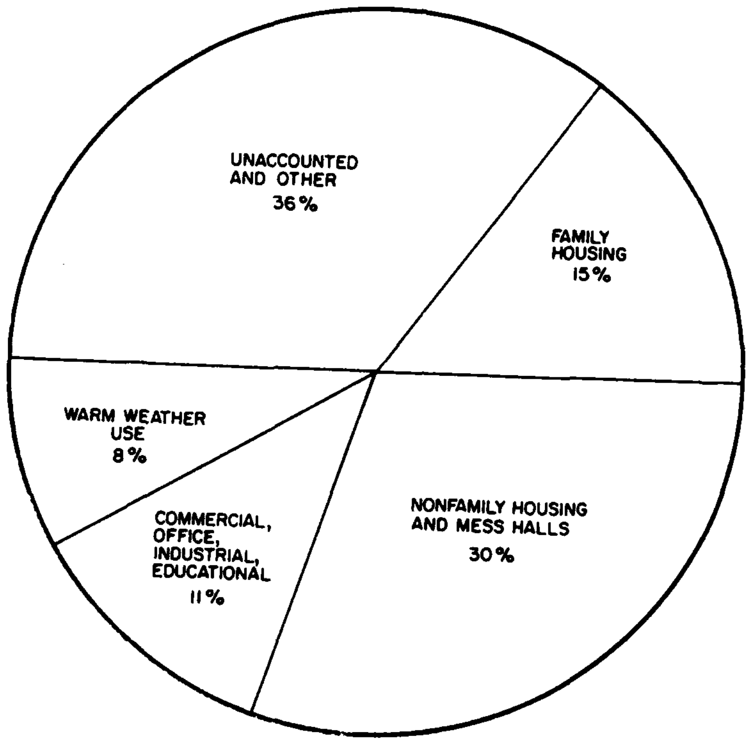


Figure 36. Yearly average water use distribution at Fort Bragg.

9 CONCLUSIONS

This study determined the proportion of potable water consumed at the four typical Army installations: Forts Bliss, Bragg, Carson, and Lewis. The results were:

1. Analysis of the present mobilization water supply planning factors supports the use of capacity factors and suggests that the 150 gpcd allotment currently assumed may be too low.

2. The largest water users on fixed installations are troop and family housing and irrigation. The amount of consumption depends on the installation's climate and on the size and composition of its on-post population. Industrial uses of water, especially for vehicle washing, are also a major component of installation water use. The information on base water users has been conveniently summarized into pie-charts to show estimated percentages of water use by user. Housing varied from 18 to 70 percent of the yearly total, and irrigation varied from 0 to 60 percent. Metering of family housing units indicates a wide range of per capita use, even in apparently identical units. Significant water savings might be realized if the few extreme water use rates (up to 11,000 gal per household per day) could be moderated.

3. Analysis of how the proportions of water use change during the year indicates that irrigation is the cause of most variation in water demand. In mid-summer, it can account for more than half the water use at an arid or semi-arid post.

REFERENCES

Brainard, F. S., "Leakage Problems and the Benefits of Leak Detection Programs," Journal American Water Works Association (February 1979), pp 64-65.

Chan, Wen-Yung and L. K. Wang, "Re-evaluating Hunter's Model for Residential Water Demand," Journal American Water Works Association, 72 (1980), pp 446-449.

Cheremisinoff, N. P. and R. A. Niles, "A Survey of Fluid Flow Measurement Techniques and Fundamentals," Water and Sewage Works (December 1975), pp 74-78.

Cole, E. S., "Methods of Leak Detection: An Overview," Journal American Water Works Association (February 1979), pp 73-75.

"Commercial Water Use," Urban Water Resources Research Program, Technical Memorandum No. 27 (American Society of Civil engineers, 1975).

Fair, Geyer, and Okun, Water Supply and Wastewater Removal (John Wiley and Sons, 1966).

Facilities Engineering Annual Summary of Operations (published annually by the office of the Chief of Engineers).

Gifft, H. M., "Establishing Variations in Domestic Sewage Flows," Water Works and Sewage, No. 92 (1945), p 175.

Girand, J., "Army Camp Water Supply Systems," Civil Engineering 13(5) (May 1943), p 219.

Greeley, S. A. and E. S. Chase, "Sanitation Facilities for Military Posts," Civil engineering 12(7) (July 1942), p 359.

Gros, W. F. H., "Leak Detection Problems in Cold Weather Conditions," Journal American Water Works Association (January 1976), pp 8-9.

Hansen, R. D., H. H. Fullerton, and T. C. Hughes, "Municipal Water Use," Utah Science, Vol 40, No. 2 (June 1979), pp 51-53.

Heim, P. M., "Conducting a Leak Detection Search," Journal American Water Works Association (February 1979), pp 66-69.

Hudson, W. D., "Increasing Water system Efficiency through Control of Unaccounted for Water," Journal American Water Works Association (July 1978), pp 362-365.

"Iowa Townspeople Install Their Own Meters," Water and Sewage Works (March 1975), pp 60-61.

Kingston, W. J., "A Do-It-Yourself Leak Survey Benefit-Cost Study," Journal American Water Works Association (February 1979), pp 70-72.

Kmenta, Jan, Elements of Econometrics (McMillan Co., 1971).

Lacina, W. V. and J. B. Coel, "Plastic Water Meters," Journal American Water Works Association (May 1976), pp 246-247.

Linaweaver, F. P. and J. C. Geyer, "Use of Peak Demands in Determination of Residential Rates," Journal American Water Works Association, 56 (1964), pp 403-410.

Matherly, J. E., et al., Water Usage Profile Fort Carson, CO, Interim Report N-34/ADA053227 (CERL, 1978).

Moyer, E. E., J. W. Male, I. C. Moore and J. G. Hock, "The Economics of Leak Detection and Repair -- A Case Study," Journal American Water Works Association, Vol 75, No. 1 (January 1983) pp 28-34.

Orr, L. E, V. A. Enna, and M. C. Miller, "Analysis of a Water-Meter Replacement Program," Journal American Water Works Association (February 1971), pp 117-122.

Pilzer, J. E.,, "Leak Detection -- Case Histories," Journal American Water Works Association (November 1981), pp 565-567.

Report on Engineering Study Water Distribution System U.S. Army Post Fort Bragg, NC, 1971 (Pitometer Associates Engineers, 1971).

Scholze, R. J., L. J. Benson, M. A. Kamiya, M. J. Staub, and J. T. Bandy, Water Conservation Methods for U.S. Army Installations: Residential Usage and Irrigation Management, Technical Report N-146 (U.S. Army Construction Engineering Research Laboratory [CERL], 1983).

Search, P. E. and T. deS. Furman, "Water Consumption by Institutions," Journal American Water Works Association, 53 (1961), pp 1111-1119.

Seidel, H. S. and J. L. Cleasby, "A Statistical Analysis of Water Works Data for 1960," Journal American Water Works Association, Vol 58 (1966), pp 1507-1527.

Seruga, E., "Sizing and Selecting Modern Water Meters," Water/Engineering and Management (January 1982), pp 40-42.

Sizing Water Service Lines and Meters, AWWA Manual M22 (American Water Works Association, 1975).

Snider, H. E., "The Metering in Water Works," Journal American Water Works Association (February 1977), pp 66-67.

Sowby, S. E., "Leak Detection Programs Recover Revenues," Journal American Water Works Association (November 1981), pp 562-564.

Water Supply Sources and General Considerations, Technical Manual (TM) 5-813-1 (Department of the Army, 1979).

Water Supply and Wastewater Removal.

Wolff, J. B., "Peak Demands in Residential Areas," Journal American Water Works Association, 53 (1961), pp 12[illegible]1-1260.

Wolfner, J. P., "Flow Metering in Water Works," Journal American Water Works Association (February 1971), pp 117-122.

APPENDIX A: FORT CARSON WATER USE

Table A1

Thousands of Gallons of Water Billed to Family Housing at Fort Carson

	Fiscal Year				Monthly	Std.
	79	80	81	82	Average	Deviation
Oct	47.3	33.2	37.2	28.2	36.5	8.1
Nov	22.9	17.3	18.3	27.8	21.6	4.8
Dec	17.2	13.9	16.2	19.5	16.7	2.3
Jan	15.2	15.7	16.5	18.1	16.4	1.3
Feb	16.1	16.4	17.5	20.1	17.5	1.8
Mar	15.2	14.3	15	16.4	15.2	0.9
Apr	22.3	14.2	36.5	27.4	25.1	9.3
May	25.5	21.3	51.6	42.4	35.2	14.2
Jun	29.5	43.6	41.6	27.9	35.7	8.1
Jul	44.9	61.2	56.1	--	54.1	8.3
Aug	51.2	67.2	41.7	--	53.4	12.9
Sep	30.5	38.6	26.8	--	32	6

Table A2

Thousands of Gallons of Water Consumed for All Purposes at Fort Carson

	Fiscal Year				Monthly	Std.
	79	80	81	82	Average	Deviation
Oct	92.3	69.6	115	92.2	64.1	18.5
Nov	67.2	46.6	78.1	81.8	65.5	15.8
Dec	70.8	47.5	45.9	76.6	57.7	15.8
Jan	65	51.1	59.6	80.6	102.7	12.4
Feb	69	56.8	63.5	72.6	88.7	6.9
Mar	52.8	44.6	67.0	66.3	117	10.9
Apr	66.9	79.4	133.3	131.3	146.6	34.5
May	69.1	75.8	107.1	102.7	123	19.0
Jun	93.1	142.8	141.3	90.8	92	28.9
Jul	117	166.4	139.5	163.4	92.3	23.1
Aug	113.3	161.7	114.8	102.1	68.4	26.4
Sep	79.6	106.3	90.1	--	60.2	13.5

Table A3

Average Monthly Water Use
at Fort Carson by Season

		Million Gallons	Std. Deviation
Winter	Nov - Mar	63.2	12
Spring	Apr - May	95.7	27
Summer	Jun - Aug	128.9	27
Autumn	Sep - Oct	92.2	15

Table A4

Family Housing Water Use by Week (From
CERL's Metering at Fort Carson)

Week	N	X	S	Week	N	X	S
1	84	98.5	81.2	27	80	339.5	301.8
2	79	104.4	96.3	28	83	353.3	261.9
3	80	103.9	95.8	29	78	266.7	263.3
4	82	101.6	114.6	30	56	296.6	245.4
5	91	119.9	140.6	31	82	306.4	296.2
6	94	115.9	122.1	32	83	284.8	273.9
7	94	127.4	126.4	33	81	350.1	468.3
8	57	77.1	49.2	34	77	211.3	238.4
9	56	80.4	58.7	35	78	233.1	252.5
10	21	87.5	41.6	36	86	137.6	156.3
11	39	110.5	75.2	37	86	178.7	187.5
12	40	101.2	74.4	38	85	211.5	181.9
13	42	124.0	149.1	39	88	216.2	174.3
14	49	129.7	129.3	40	86	207.5	308.6
15	71	212.5	199.1	41	82	187.6	249.5
16	71	206.8	260.0	42	83	113.7	89.3
17	69	120.3	97.1	43	83	99.1	75.1
18	72	126.4	125.0	44	89	101.6	86.1
19	69	124.3	137.5	45	90	81.7	61.8
20	75	115.7	183.3	46	54	88.5	73.5
21	76	310.4	272.9	47	53	79.5	73.4
22	79	349.6	359.1	48	89	87.2	69.4
23	86	289.2	218.8	49	90	96.1	78.0
24	86	313.4	213.4	50	88	97.1	63.1
25	81	383.6	321.3	51	51	82.1	60.3
26	80	284.9	236.2	52	54	82.0	66.2

N = number of housing units with valid data
X = average per capita use (gallons)
S = sample standard deviation (gallons)

Table A5

FY 81 Reimbursable Billings - Fort Carson

	Thousands of Gallons
Government:	
Bergstrom AFB	81.84
Commissary	1492.90
Family Housing	374,832.60
NORAD	16,105.10
Officers' Club	148.32
Package Bev. Stores	1210.30
DPDO	42.60
Rocky Mtn. Area Exchange	8856.67
COE	
Subtotal	402,770.33
Other:	
AG of Colorado	768.00
Credit Union	70.00
Fort Carson National Bank	92.10
School District 8	1982.24
Subtotal	2912.34
Contractors:	
Fashion Cleaners	0
Bowman Roofing	-
Garcia Concrete	2
Carson Cable Television	-
Mondos Paint	-
Hubcon Corp	30
Cowper Construction	3166.20
Hensel Phelps	3036.60
Macs Houston	104.70
Sharp Bros.	2330.00
Reid Construction	357.70
Sauter Construction	6881.20

Table A6

Fort Carson - Gallons Effluent to Golf Course

Jul 82	15,125,380
Jun 82	6,642,860
May 82	5,251,880
Apr 82	11,752,240
Mar 82	5,320,670
Feb 82	0
Apr 80	7,238,130
May 80	6,351,140
Jun 80	21,178,680
Jul 80	6,023,100
Aug 80	14,847,700
Sep 80	9,898,350
Oct 80	3,365,670
Nov 80	2,092,340

From March 1980 to July 1982 190,229,230 gal

Average = 6,793,901 gal/month
or 6794 Kgal/month

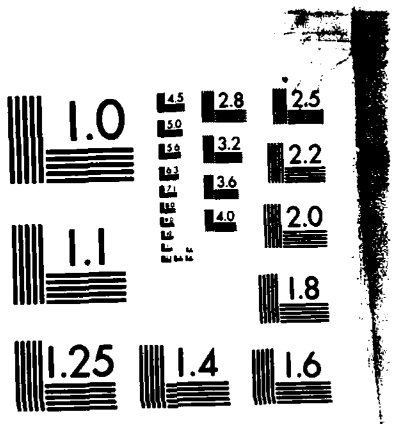
APPENDIX B: FORT LEWIS WATER USE HISTORICAL RECORDS

(Thousand Gallons)

	J	F	M	A	M	J	J	A	S	O	N	D
Camp Murray	26	680	266	166	160	471	1457	2643	3771	2158	609	2908
Madigan	7456	8341	2127	8759	8229	10800	18431	43291	36331	4712	10605	9661
Vets Hospital	2500	2323	3545	3852	3222	3159	5525	9833	9286	4052	3139	2715
Golf Course #9 Well	66	36	30	56	63	74	166	466	209	174	55	47
Dupont	1	2	6	5	14	10	157	664	43	12	41	2
Laundry	2437	3393	3181	3013	2495	2992	3520	3527	2825	3417	8773	2478
Bus Garage	34	32	24	28	28	29	23	28	29	27	31	27
Pilot Plant	23461	18219	14500	14318	12437	10633	8132	8141	10647	11600	--	--
Beechwood School	13	16	14	18	14	14	32	46	15	15	16	13
Officers Bch.	0	0	0	0	0	1	8	17	3	0	0	0
Beechwood Shoppette	3	4	2	3	3	4	5	5	4	3	3	3
Hillside School	23	47	44	30	109	21	3	3	29	48	43	53
PX Car Wash	965	1146	1163	1338	1359	1398	170	107	81	46	76	58
Parkway School	10	31	17	26	51	121	141	462	119	92	151	23
PX Fast Fd. Fac.	31	42	41	40	39	42	46	58	86	38	42	35
Liquor Store	3	2	2	2	2	2	2	2	2	2	3	4
Commissary	Est.900	--	--	--	--	--	--	--	--	--	--	--
Credit Union	10	11	10	11	10	19	58	120	112	25	7	8
PX Cafeteria	378	178	156	170	154	605	15	344	187	213	240	258
Main PX	27	41	27	--	--	--	191	44	36	29	37	42
Bank	8	9	9	14	31	58	61	64	76	37	14	16
Ft. Lewis Lodge	387	345	306	328	349	389	143	693	605	446	590	415
Clarkmoor School	2	2	2	2	3	2	1	2	2	3	2	2
O. Club Total	336	501	340	450	613	942	3397	4615	6038	803	--	--
O. Club Irrig.	--	--	--	--	--	459	1110	1484	1738	1452	2230	1733
3rd Bde PX	20	21	24	24	24	28	26	23	27	25	25	24
W. Natl. Gd	4	5	1	0	5	7	9	95	92	78	76	97
Donut Shop #3293	1	1	3	1	1	1	1	1	1	1	1	1
B. Alley #2272	61	67	61	61	51	51	370	873	923	118	58	58
Kimbro Pool	553	578	796	975	994	374	94	237	521	164	176	72
NCO Club #8085	156	141	148	136	112	116	235	379	228	190	123	117
N.F. Ballfield #341	0	0	0	0	0	6	394	466	1713	42	0	0
S.F. Ballfield	0	0	0	0	0	0	278	580	60	50	0	0
Greenwood School	65	50	55	34	43	37	17	4	43	65	72	49

AD-A133 232 DISTRIBUTION OF WATER USE AT REPRESENTATIVE FIXED ARMY INSTALLATIONS(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL J T BANDY ET AL. AUG 83 2/2

UNCLASSIFIED CERL-TR-N-157 F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C: FORT BLISS WATER USE

Table C1

Water Purchased in Cantonment Area for
Fort Bliss in Thousands of Gallons
(Source: Utility Office Records)

	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982
Oct	39502	39973	62857	32290	34277
Nov	28098	17893	31220	20950	30637
Dec	25115	22848	28389	29807	24933
Jan	24742	23149	30678	25227	24631
Feb	24850	23776	24522	29899	28121
Mar	48994	50089	35979	37937	47161
Apr	69888	72908	51113	49424	64330
May	91620	89174	74757	68439	72718
Jun	122298	111529	106832	116143	122371
Jul	112309	122009	119431	93370	96718
Aug	85390	72062	69411	51217	
Sep	39919	68232	51478	53545	

Table C2

Total Water Purchased from El Paso
(From Water Office Records
(Thousand Gallons)

	1977	1978	1979	1980	1981	1982
Oct	34936	45721	45673	70921	38057	35577
Nov	27381	32369	27924	37056	25617	34513
Dec	30504	29223	26760	31997	35491	29674
Jan	28093	29109	27260	37437	30036	32891
Feb	38491	28709	28546	28805	34193	32301
Mar	61397	53551	55864	41390	43052	51066
Apr	79363	73898	78386	56082	54686	68105
May	112935	98368	95870	81128	73824	77604
Jun	133996	128857	118003	114649	123655	128765
Jul	115191	118987	130577	127779	100450	
Aug	112116	92072	81954	84303	61987	
Sep	89361	45217	78243	58992	59526	

Table C3

Fort Bliss Produced Water
(Thousand Gallons)

	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982
Oct	104148	93559	114605	99718	109642
Nov	89281	81920	77817	80568	84831
Dec	81/38	81135	73946	78570	79240
Jan	80627	81241	81474	82702	79808
Feb	76546	75636	80809	81202	81255
Mar	117944	105699	103457	98296	106537
Apr	160397	133179	125497	124390	139407
May	198147	174832	177041	1581/1	175992
Jun	249264	239623	257710	223223	228265
Jul	242624	268616	254551	201130	204892
Aug	201953	170504	196511	151740	
Sep	128395	160533	129797	133260	

Table C4

Total Water Available Purchased and Produced
(Million Gallons)

FY	QTR	PURCH	PROD	YEAR TOTAL	
78	1	92.716	275.167	367.883	
	2	98.587	275.117	373.704	2444
	3	283.806	607.808	891.614	
	4	237.619	572.972	810.591	
79	1	80.714	256.614	337.328	
	2	97.015	262.576	359.591	2380
	3	273.607	547.634	821.241	
	4	262.304	599.653	861.957	
80	1	122.467	266.368	388.835	
	2	91.179	265.740	356.919	2360
	3	232.702	560.248	792.950	
	4	240.320	580.859	821.179	
81	1	83.048	258.856	341.904	
	2	93.064	262.200	355.264	2121
	3	234.006	505.784	739.790	
	4	198.133	486.130	684.263	
82	1	89.848	273.713	363.561	
	2	99.913	267.600	367.513	
	3	259.421	543.664	803.085	
AVG	1			359.902	
	2			362.598	2327
	3			809.736	
	4			794.498	

Table C5

Purchased Water for Logan Heights Area
Includes: Golf Course, Housing, and Basic
Training Barracks
(Thousand Gallons)

	1977	1978	1979	1980	1981	1982
Oct	18185	18543	11854	30134	13235	15578
Nov	15575	13583	7643	15025	8057	14918
Dec	18185	11994	9241	12729	13085	10982
Jan	14551	10755	7744	14504	11196	10310
Feb	16857	10566	8146	6740	13507	14135
Mar	28950	25766	22780	11251	17553	23659
Apr	39262	41778	34289	20560	24356	36001
May	55918	51011	45527	36000	36726	38408
Jun	68339	61491	56382	58916	62573	67902
Jul	58542	55493	57517	64276	48635	
Aug	51547	40454	35769	32951	21533	
Sep	41471	15516	33737	25401	28307	

Table C6

Purchased Water for Aero Vista Housing Area
(Thousand Gallons)

	1977	1978	1979	1980	1981	1982
Oct	9892	10438	14632	19958	10432	9912
Nov	8174	7131	7834	8298	6800	8444
Dec	6988	6426	7492	8042	8435	8143
Jan	7353	7170	8381	8832	7027	7735
Feb	9504	7781	9248	10496	8902	7881
Mar	15293	11054	17042	14236	11570	14017
Apr	19073	11336	23494	18718	14660	17892
May	26750	19808	26750	23351	18810	20677
Jun	31190	35803	35253	24927	32374	32472
Jul	26695	32020	37178	31679	25298	
Aug	28521	27300	19963	29170	17452	
Sep	22099	14484	20143	14884	14385	

Table C7

Water Pumped From 600,000 Tank to 1,000,000
WBAMC, i.e., Upper Beaumont
Includes: New Hospital, Housing, 2 Barracks, 1 Institute
(Thousand Gallons)

	1977	1978	1979	1980	1981	1982
Oct	10343	10088	11575	14360	11419	11695
Nov	9849	9539	8526	8968	10218	11677
Dec	8935	8123	8758	8882	11318	11677
Jan	9904	8966	10235	10296	10489	10417
Feb	8644	6942	9567	9658	10420	9673
Mar	12332	8457	9951	12266	12273	12693
Apr	7511	13783	14134	14592	15327	16846
May	16510	16783	15539	15210	15696	15761
Jun	18900	19101	17867	25278	23976	25255
Jul	23039	19626	21813	22140	20873	
Aug	18993	13277	14427	16528	16605	
Sep	15450	15261	13910	12903	14995	

Table C8

Water Usage in Thousand Gallons Billed or Otherwise
Accounted for by the Utility Office at Fort Bliss
(Most Values Are Estimates)

FY 1978

Consumer	O	N	D	J	F	M	A	M	J	J	A	S
CXO	3034	2071	2690	2760	2730	2984	3267	2874	2871	3305	3123	3048
Rod & Gun Club	7	7	7	7	7	7	7	7	7	7	7	7
Aero Flying Club	7	7	7	7	7	7	7	7	7	7	7	7
Saddle Club	109	109	109	·109	109	109	109	109	109	109	109	109
Guest Houses	427	427	427	427	427	427	427	427	427	427	427	427
Golf Assn	156	156	156	156	112	156	156	156	156	156	156	156
Community College	479	440	369	164	439	401	593	301	577	787	344	263
El Paso Natl Bank	8	8	8	8	8	8	8	8	8	12	12	12
State Natl Bk	8	8	8	8	8	8	8	8	8	8	8	8
Credit Union	31	25	21	20	17	20	15	46	28	29	31	25
Mt. Bell Teleph.	4	4	4	4	4	4	4	4	4	4	4	4
Off. Wives	4	4	4	4	4	4	4	4	4	—	—	—
Kelly Park	3738	3447	2049	1997	2040	2105	2105	2527	765	493	496	414
Private Contract.	473	399	449	313	295	-57	245	159	189	214	69	114
Allied Officers	314	314	314	308	312	297	308	308	285	199	210	210
Natl. Cem	853	378	343	408	452	438	1730	2084	2841	2557	1822	1756
U.S. Cust. Serv.	48	48	48	48	48	52	52	52	52	52	52	52
Marine Corps	36	36	36	35	35	35	35	11	11	11	11	11
NM Natl Gd.	200	200	200	215	215	748	205	205	205	205	205	205
C of E-FW	44	44	44	39	39	42	42	42	42	42	42	42
Commissary	1735	1735	1735	1735	1735	1735	962	962	185	2647	2647	2647
Def. Aud. Agy.	13	13	13	13	13	17	17	17	17	17	17	17
Kuwait Air Def.		342	171	151	151	122	122	122	122	122	122	122
Reserve Comp.			147			455			74			132
Def. Com. Adm.				4	4	8	4	7	7	-15	29	7
Jordan Mls. Sys.						70	70	70	70	70	70	70

Table C9

Water Usage in Thousand Gallons Billed or Otherwise
Accounted for by the Utility Office at Fort Bliss
(Most Values Are Estimates)
FY 1979

Consumer	O	N	D	J	F	M	A	M	J	J	A	S
CXO	3214	2737	2986	2912	2808	2808	3066	2979	3149	3106	3146	3146
Rod & Gun Club	7	7	7	7	5	7	7	7	7	7	7	7
Aero Flying Club	7	7	7	7	5	2	2	2	2	2	2	2
Saddle Club	109	109	109	109	109	109	109	109	109	109	109	109
Guest Houses	427	435	435	435	435	435	435	435	435	435	435	435
Golf Assn.	156	156	91	91	91	91	91	91	91	91	91	91
Community College	417											
El Paso Natl. Bk	12	12	12	9	8	11	11	11	11	11	11	11
State Natl. Bk	8	8	8	6	8	8	8	8	8	8	8	8
Credit Union	36	49	66	72	70	24	34	28	28	29	31	25
Mt. Bell Teleph.	4	4	4	3	3	3	3	3	3	3	3	3
Off. Wives	4	4	4	3	3	3	3	3	3	3	3	3
Kelly Park	16	32	32	16	16	8	9					
Private Contract.	140	86	66	66	66	66	66	66	39	39	39	181
Allied Officers	210	201	294	248	175	176	176	176	174	176	176	211
Natl. Cem.	341	585	551	239	327	620	7781	4398	6885	8885	6351	6627
U.S. Cust. Serv.	52	52	52	52	9	89	28	28	28	28	28	89
Marine Corps	11	11	11	11	11	119	119	119	119	119	119	119
NM Natl. Gd.	205	205	205	205	205	205	205	205	205	205	205	205
C of E-FW	42	42	42	42	42	30	30	30	30	30	30	30
Commissary	2934	2934	2934	1454	1365	2060	1227	1227	53	555	445	298
Def. Aud. Agy.	17	17	17	17	17	14	14	14	14	14	14	14
Kuwait Air Def.	122	122	243CR	630	134	134	134	435	435	672		332
Def. Cont. Adm.	7	7	7	7	5	29	28	28	28	28	28	28
Jordon Msl. sys.	70	70	139CR	—	412	82	268	268	268	220		1025
Recreation Svcs.		634	423	423	423	423	499	423	505	436	436	436
Reserve Comp.			77			57		—	553			376
WBAMC Rec SVCS								77	77	77	77	77
Def. Inv. Serv.										67		67

Table C10

Water Usage in Thousand Gallons Billed or Otherwise
Accounted for by the Utility Office at Fort Bliss
(Most Values Are Estimates)
FY 1980

Consumer	O	N	D	J	F	M	A	M	J	J	A	S
CXO	3341	3631	3749	3443	3333	3005	3153	2946	2981	3123	3227	2940
Rod & Gun Club	7	7	7	7	7	7	7	7	7	7	7	7
Aero Flying Club	2	2	2	2	2	2	2	2	2	2	2	2
Saddle Club	109	109	109	109	109	109	109	109	109	109	109	109
Guest Houses	435	435	435	435	435	435	435	435	435	435	435	435
Golf Assn.	91	7983	1043	2197	1978	—						
Rec. SVCS	436	436	436	436	436	13	13	13	13	13	13	13
El Paso Natl. Bk.	11	11	11	11	11	11	11	11	11	11	11	11
State Natl. Bk.	8	8	8	8	8	8	8	8	8	8	8	8
Credit Union	38	35	30	29	29	30	42	36	41	55	58	39
Mt. Bell Teleph.	3	3	3	3	3	3	3	3	3	3	3	3
Off. Wives	3	3	3	3	3	3	3	3	3	3	3	3
WBAMC SVCS	77	77	77	77	295	219	219	219	219	219	219	219
Private Contract.	78	1093	179	256	174	32	17	13	11	1		
Allied Officers	211	211	211	211	139	94	94	115	115	115	115	115
Ntl. Cem.	8054	4090	527	460	441	734	2567	5661	7586	13277	7021	757
U.S. Cust. Serv.	28	28	89	28	28	89	28	16	77	16	16	77
Marine Corps	119	119	119	119	119	119	119	119	119	119	119	119
NM Natl. Gd.	205	205	205	205	205	205	205	205	205	205	205	205
C of E-FW	30	30	38	30	77	83	30	30	30	30	30	30
Commissary	437	3456	542	1195	518	292	367	311	554	464	493	490
Def. Aud. Agy.	14	14	14	14	14	14	14	14	14	14	14	14
Def. Cont. Adm.	28	28	28	28	28	28	28	28	28	28	28	28
Ft. Bliss Off. Club		119	79		79	79	79	79	79	79	79	79
WBAMC Off. Club		174	116	195	116	116	23	23	23	23	23	23
Reserve Comp.			986									
Kuwait Air Def.			332			332			332			332
Jordan Msl. Sys.			1025			1025			1025			1025
Def. Inv. SVCS.			67			67						
Pueblo Depot				122	31	31	31	31	31	31	31	31
Franklin Cablevision							20	20	20	20	20	20
C of E, Dental Clinic							8	10	3	3	10	10
El Paso Field Serv.									67			67
U.S. Army OTEA												1037

Table C11

Water Usage in Thousand Gallons Billed or Otherwise Accounted for by the Utility Office at Fort Bliss (Most Values Are Estimates)

FY 1981

Consumer	O	N	D	J	F	M	A	M	J	J	A	S
CXO	3174	2733	2524	2515	2480	2547	2795	2698	2792	3057	3234	2636
Rod & Gun Club	7	7	7	7	7	7	7	7	7	7	7	7
Aero Flying Club	2	2	2	2	2	2	2	2	2	2	2	2
Saddle Club	109	109	109	109	109	109	109	109	109	109	109	109
Guest houses	435	435	435	435	435	435	435	435	435	435	435	435
WBAMC Guest Hses.	219	219	219	219	219	219	219	214	214	214	214	214
Rec. SVCS	13	13	13	13	13	13	13	13	13	13	13	13
El Paso Natl Bk	11	11	11	11	11	11	22	11	25	41	17	9
State Natl Bk	8	8	8	8	8	8	16	8	8	21	21	8
Credit Union	48	32	33	34	38	33	43	43	87	150	—	
Mt. Bell Telep.	3	3	3	3	3	3	3	3	3	3	3	3
Off. Wives	3	3	3	3	3	3	3	3	3	3	3	3
Franklin Cablevision	20	20	20	20	20	20	20	20	20	20	20	20
Private Contract	1											
Allied Officers	-	132	132	133	135	124	125	125	125	115	115	115
Natl Cem.	167	204	120	131	289	1290	4516	3930	8007	6369	3430	2073
U.S. Cust. Serv.	16	16	77	16	16	77	16	16	77	16	16	77
Marine Corps	119	119	119	119	0	—	—					
NM Natl Gd	205	205	205	205	205	205	205	205	205	205	205	205
C of E-FW	30	30	30	30	30	30	30	30	30	30	30	30
Commissary	507	606	390	459	558	366	378	331	427	353	416	339
Def. Aud. Agy.	14	14	14	14	14	14	14	14	14	14	14	14
Def. Contr. Adm.	28	28	28	28	28	28	28	28	28	28	28	28
Pueblo Depot	31	31	31									
Ft. Bliss Off. Club	79	79	79	79	79	79	79	44	258	468	160	97
WBAMC Off. Club	23	23	23	23	23	23	23	23	23	23	23	23
C of E Dental Clinic	10	10	10	10								
U.S. Army OTEA	40	40	40	40	40	40	40	40	40	40	40	40
Property Disp. Off.	36	36	36	36	36	36	36	36	36	36	36	36
Army Res. Inst.	135	135	135	135	135	135	135	135	135	135	135	135
US Army Air Def. Bd.	1113	1113	1113	1113	1113	1113	1113	1113	1113	1113	1113	1113
El Paso Fld Serv.			61			67			67			67
Patriot Trng. Fac					390							
Golf Assn.						113	113	113	113	113	113	113
Jordan Msl.						1025			342			1025
Kuwait						332			111			332
G. Bradley's Home										56	75	75

Table C12

Water Usage in Thousand Gallons Billed or Otherwise Accounted for by the Utility Office at Fort Bliss (Most Values Are Estimates)

FY 1982

Consumer	O	N	D	J	F	M	A	M	J	J	A	S
CXO	2807	2656	2473	2464	2464	2444	2623	2673	2431	2694	2735	
Rod & Gun Club	7	7	7	7	7	7	7	7	7	7	7	
Aero Flying Club	2	2	2	2	2	5	5	5	5	5	5	
Saddle Club	109	109	109	109	109	109	109	109	109	109	109	
Guest Houses	435	435	435	435	435	435	435	435	435	435	435	
Golf Assn.	113	113	113	113	113	113	113	113	113	113	113	
WBAMC Guest Houses	214	214	214	214	214	214	214	214	214	214	214	
El Paso Natl. Bk.	21	18	9	20	20	18	20	20	19	19	19	
State Natl. Bk.	8	8	29	162	345	165	363	386	290	261	387	
Franklin Cablevision	20	20	20	20	20	4	4	4	15	45	15	
Mt. Bell Telep.	3	3	3	3	3	3	3	3	3	3	3	
Off. Wives	3	3	3	3	3	3	3	3	3	3	3	
Def. Cont. Adm.	28	28	28	28	28	28	28	28	28	28	28	
U.S. Army OTEA	80	80	80	80	80	80	80	80	80	80	80	
Allied Officers	107	107	107	108	108	86	86	86	86	102	102	
Natl. Cem.	446	389	158	153	577	735	4075	6198	6714	6473	6228	
U.S. Cust. Serv.	16	16	77	16	16	77	16	16	77	16	16	
US Army Air Def. Bd.	1113	1113	1113	1113	1113	1113	1057	1057	1057	1057	1057	
NM Natl. Gd.	205	205	205	205	205	205	205	205	205	205	205	
C of E-FW	30	30	30	30	30	30	30	30	30	30	30	
Commissary	561	534	351	304	244	308	466	419	434	536	699	
Def. Aud. Agy.	14	14	14	14	14	14	14	14	14	14	14	
Rec. Svcs.	13	13	13	13	13	13	13	13	13	13	13	
Ft. Bliss Off. Club	34	31	26	—	54	52	59	314	997	1209	980	
WBAMC Off. Cl.	23	23	23	55	—	—	—	—	—	—	—	
PDO	36	36	36	36	36	36	36	36	36	36	36	
Army Research	135	135	135	135	135	135	135	135	135	135	135	
U.S. Post Office		43	43	43	43	43	43	43	43	43	43	
E.P. Roundhouse		5	5	5	5	—	—	—	—	—	—	
Credit Union			538	68	90	81	94	59	72	102	101	
Jordan			1025			1025			1025			
Kuwait			332			332			332			
E.P. Field Inv. Svc.			67			67			67			
TX Air Natl. Gd.			11	11	11	11	11	11	11	11	11	

Table C13

Population at Fort Bliss From
Population Performance Factors (Comptroller)

Month	Resident	Transient and Civilian	Population Equivalent
		FY 1982	
Dec	22497	+(1/3) 14452	= 27314
Jan	23756	" 14464	28577
Feb	24184	" 14531	29028
Mar	24358	" 14626	29233
Apr	31619	" 15119	36659
May	25359	" 15184	30420
Jun	25043	" 15064	30064
Jul	24408	" 14984	29403
		FY 1981	
Oct	23843	+(1/3) 14138	28556
Nov	23474	" 14161	28194
Dec	22905	" 13727	27481
Jan	23255	" 13894	27886
Feb	23450	" 14108	28153
Mar	27290	" 14022	31964
Apr	26660	" 14494	31491
May	24774	" 14163	29495
Jun	24690	" 13846	29305
Jul	23250	" 14077	27942
Aug	24612	" 14088	29308
Sep	24295	" 14566	29150
		FY 1980	
Nov	23126	" 13971	27783
Dec	22019	" 13620	26559
Jan	22204	" 13536	26716
Feb	22766	" 13655	27318
Mar	22878	" 13637	27424
Apr	22866	" 13531	27376
May	23083	" 13439	27563
Jun	22992	" 13398	27458
Jul	23061	" 14042	27742
Aug	22961	" 13731	27538
Sep	23164	" 13742	27745

Table C13 (Cont'd)

		FY 1979	
Oct	20972	+(1/3) 15734	26217
Jul	20677	" 16198	26076
Aug	21384	" 16496	26883
Sep	22999	" 13935	27644
		FY 1978	
Oct	22634	+(1/3) 20356	29419
Nov	22763	" 20361	29550
Dec	21239	" 20388	28035
Jan	23408	" 20318	30181
Feb	22662	" 20176	29387
Mar	21823	" 20248	28572
Apr	21603	" 20082	28297
May	22772	" 19891	29402
Jun	24364	" 19418	30837
Jul	21725	" 19543	28239
Aug	20782	" 19897	27414

Table C14

Population (Effective)

FY	QTR	Res. Pop.	Eff. Pop.
78	1	22212	29001
	2	22631	29380
	3	22913	29512
	4	21254	27827
79	4	21687	26868
80	1	22573	27171
	2	22616	27153
	3	22980	27466
	4	23062	27675
81	1	23407	28077
	2	24665	29334
	3	25375	30097
	4	24052	28800
82	1	——	——
	2	24099	28946
	3	27340	32381

Table C15

Water Used in Three Steam Plants
Soft Water Produced (in Gallons)
Building and Number

Month	WBAMC #7776	WBAMC #7145	Center Laundry #2033
		FY 1982	
Oct	907200	—	900869
Nov	802800	220400	954900
Dec	579200	170200	772700
Jan	681900	18600	725300
Feb	657100	42200	734300
Mar	725300	222300	849900
Apr	678200		882300
May	664200		800200
Jun	717100		1022300
Jul	657700		874400
		FY 1981	
Oct	1028200	66500	904700
Nov	1036000	184800	771700
Dec	886300	589700	762100
Jan	732700	425400	969000
Feb	743900	237300	893400
Mar	952700	286100	964600
Apr	736300	183200	966700
May	815800		938000
Jun	846200		915600
Jul	815300		969900
Aug	758700		936300
Sep	826100		962100
		FY 1980	
Oct	775600		1076500
Nov		296900	858600
Dec	METER	277900	731500
Jan	DEFECTIVE	310300	834100
Feb		243600	773300
Mar	65000	220100	872000
Apr	876400	265300	938700
May	657000		945000
Jun	785000		933000
Jul	677900		1078000
Aug	642800		1056900
Sep	683000		882000

Table C15 (Cont'd)

FY 1979

Oct	603700	48000	1189000
Nov	635700	217100	1125800
Dec	398200	226000	863300
Jan	757800	263800	977400
Feb	893400	214500	903800
Mar	1019100	265300	1068000
Apr	891400	—	929900
May	892600	—	997200
Jun	792700	—	983200
Jul	768300	—	964100
Aug	742500	—	816600
Sep	716500	—	1063200

FY 1978

Oct	481600	154100	1101600
Nov	547800	531800	1036000
Dec	560000	527600	957400
Jan	607200	410900	1062100
Feb	612000	302700	1210700
Mar	1440400	238300	705500
Apr	554100	—	1169100
May	548100	—	1300700
Jun	466300	—	1288200
Jul	410100	—	837500
Aug	508500	—	968200
Sep	532100	—	772000

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWR-W
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ZCF
ATTN: DAEN-ECB
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZCZ
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

FESA, ATTN: Library 22060

FESA, ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library
Alaska 99501
Al Batin 09616
Albuquerque 87103
Baltimore 21203
Buffalo 14207
Charleston 29402
Chicago 60604
Detroit 48231
Far East 96301
Fort Worth 76102
Galveston 77550
Huntington 25721
Jacksonville 32232
Japan 96343
Kansas City 64106
Little Rock 72203
Los Angeles 90053
Louisville 40201
Memphis 38103
Mobile 36628
Nashville 37202
New England 02154
New Orleans 70160
New York 10007
Norfolk 23510
Omaha 68102
Philadelphia 19106
Pittsburgh 15222
Portland 97208
Riyadh 09038
Rock Island 61201
Sacramento 95814
San Francisco 94105
Savannah 31402
Seattle 98124
St. Louis 63101
St. Paul 55101
Tulsa 74102
Vicksburg 39180
Walla Walla 99362
Wilmington 28401

US Army Engineer Divisions
ATTN: Library
Europe 09757
Huntsville 35807
Lower Mississippi Valley 39180
Middle East 09038
Middle East (Rear) 22601
Missouri River 68101
North Atlantic 10007
North Central 60605
North Pacific 97208
Ohio River 45201
Pacific Ocean 96858
South Atlantic 30303
South Pacific 94111
Southwestern 75202

US Army Europe
HQ, 7th Army Training Command 09114
ATTN: AETTG-DEH (5)
HQ, 7th Army ODCS/Engr. 09403
ATTN: AEAEN-EH (4)
V. Corps 09079
ATTN: AETVDEH (5)
VII. Corps 09154
ATTN: AETSDEH (5)
21st Support Command 09325
ATTN: AEREH (5)
Berlin 09742
ATTN: AEBA-EN (2)
Southern European Task Force 09168
ATTN: AESE-ENG (3)
Installation Support Activity 09403
ATTN: AEUES-RP

8th USA, Korea
ATTN: EAFE (8) 96301
ATTN: EAFE-Y 96358
ATTN: EAFE-ID 96224
ATTN: EAFE-4M 96208

8th USA, Korea
ATTN: EAFE-H 96271
ATTN: EAFE-P 96259
ATTN: EAFE-T 96212

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

USA Japan (USARJ)
Ch, FE Div, AJEN-FE 96343
Fac Engr (Honshu) 96343
Fac Engr (Okinawa) 96331

Rocky Mt. Area 80903

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Western Area Office, CE
Vanderberg AFB, CA 93437

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science
ATTN: DSCPER/MAEN-A

Engr. Studies Center 20315
ATTN: Library

AMMRC, ATTN: DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

DARCOM - Dir., Inst., & Svcs.
ATTN: Facilities Engineer
ARRADCOM 07801
Aberdeen Proving Ground 21005
Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot 78419
Harry Diamond Laboratories 20783
Dugway Proving Ground 84022
Jefferson Proving Ground 47250
Fort Monmouth 07703
Letterkenny Army Depot 17201
Natick R&D Ctr. 01760
New Cumberland Army Depot 17070
Pueblo Army Depot 81001
Red River Army Depot 75501
Redstone Arsenal 35809
Rock Island Arsenal 61299
Savanna Army Depot 61074
Sharpe Army Depot 95331
Seneca Army Depot 14541
Tobyhanna Army Depot 18466
Tooele Army Depot 84074
Watervliet Arsenal 12189
Yuma Proving Ground 85364
White Sands Missile Range 88002

DLA ATTN: DLA-WI 22314

FORSCOM
FORSCOM Engineer, ATTN: AFEN-FE
ATTN: Facilities Engineer
Fort Buchanan 00934
Fort Bragg 28307
Fort Campbell 42223
Fort Carson 80913
Fort Devens 01433
Fort Drum 13601
Fort Hood 76544
Fort Indiantown Gap 17003
Fort Irwin 92311
Fort Sam Houston 78234
Fort Lewis 98433
Fort McCoy 54656
Fort McPherson 30330
Fort George G. Meade 20755
Fort Ord 93941
Fort Polk 71459
Fort Richardson 99505
Fort Riley 66442
Presidio of San Francisco 94129
Fort Sheridan 60037
Fort Stewart 31313
Fort Wainwright 99703
Vancouver Bks. 98660

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch, Instl. Div.
ATTN: Facilities Engineer
Arlington Hall Station (2) 22212
Vint Hill Farms Station 22186

MDW
ATTN: Facilities Engineer
Cameron Station 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer
Oakland Army Base 94626
Bayonne MOT 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 071160

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-FE
ATTN: Facilities Engineer
Fort Belvoir 22060
Fort Benning 31905
Fort Bliss 79916
Carlisle Barracks 17013
Fort Chaffee 72902
Fort Dix 08640
Fort Eustis 23604
Fort Gordon 30905
Fort Hamilton 11252
Fort Benjamin Harrison 46216
Fort Jackson 29207
Fort Knox 40121
Fort Leavenworth 66027
Fort Lee 23801
Fort McClellan 36205
Fort Monroe 23651
Fort Rucker 36362
Fort Sill 73503
Fort Leonard Wood 65473

TSARCOM, ATTN: STSAS-F 63120

USACC
ATTN: Facilities Engineer
Fort Huachuca 85613 (2)
Fort Ritchie 21719

WESTCOM
ATTN: Facilities Engineer
Fort Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Survivability Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22060
ATTN: ATZA-DTE-EM
ATTN: ATZA-DTE-SW
ATTN: ATZA-FE
ATTN: Engr. Library
ATTN: Canadian Liaison Office (2)
ATTN: IWR Library

Cold Regions Research Engineering Lab 03755
ATTN: Library

ETL, ATTN: Library 22060

Waterways Experiment Station 39180
ATTN: Library

HQ, XVIII Airborne Corps and 28307
Ft. Bragg
ATTN: AFZA-FE-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB 92409
ATTN: AFRCE-MX/DEE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAFEC
ATTN: RDT&E Liaison Office
Atlantic Division 23511
Chesapeake Division 20374
Southern Division 29411
Pacific Division 96860
Northern Division 19112
Western Division 64066
ATTN: Sr. Tech. FAC-03T 22332
ATTN: Asst. CDR R&D, FAC-03 22332

NCEL 93041
ATTN: Library (Code L08A)

Defense Technical Info. Center 22314
ATTN: DDA (12)

Engineering Societies Library 10017
New York, NY

National Guard Bureau 20310
Installation Division

US Government Printing Office 22304
Receiving Section/Depository Copies (2)

US Army Env. Hygiene Agency
ATTN: HSHB-E 21010

Bandy, John T.
Distribution of water use at representative fixed Army installations / by John T. Bandy, Richard J. Scholze. - Champaign, IL ; Construction Engineering Research Laboratory ; available from NTIS, 1983.
107 p. (Technical report / Construction Engineering Research Laboratory ; N-157)

1. Water consumption. 2. Ft. Bliss, TX. 3. Ft. Bragg, NC. 4. Ft. Carson, CO. 5. Ft. Lewis, WA. I. Scholze, Richard J. II. Title. III. Series ; Technical report (Construction Engineering Research Laboratory) ; N-157.

END

FILMED

10-83

DTIC